EIGHTH EDITION

Welding

Principles and Applications

Larry Jeffus

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This book is dedicated to two very special people—my daughters Wendy and Amy.

Contents

Preface

Introduction

The welding industry presents a continuously growing and changing series of opportunities for skilled welders. Even with economic fluctuations, the job outlook for skilled welders is positive. Due to a steady growth in the demand for goods fabricated by welding, new welders are needed in every area of welding, such as small shops, specialty fabrication shops, large industries, and construction. The student who is preparing for a career in welding will need to:

- be alert and work safely.
- have excellent hand–eye coordination.
- work well with tools and equipment.
- have effective written and verbal communications skills.
- be able to resolve basic mathematical problems.
- be able to follow written and verbal instructions.
- work with or without close supervision.
- work well individually and in groups.
- read and interpret welding drawings and sketches.
- know the theory and application of the various welding and cutting processes.
- be computer literate.

A thorough study of *Welding: Principles and Applications* in a classroom/shop setting will help students prepare for opportunities in welding technology. The comprehensive technical content provides the basis for the welding processes. The extensive descriptions of equipment and supplies, with in-depth explanations of their operation and function, are designed to familiarize students with the tools of the trade. The process descriptions, practices, and experiments coupled with actual performance teach the critical fabrication and welding skills required on the job. The text also discusses occupational opportunities in welding and explains the training required for certain welding occupations. The skills and personal traits recommended by the American Welding Society (AWS) for its SENSE (School Excelling through National Skill Standards Education) Welder Certification program are included within the text.

The National Center for Welding Education and Training, known as Weld-Ed, is a partnership between business and industry, community and technical colleges, universities, the American Welding Society, and government to promote welding education.

Organization

The text is organized to guide the student's learning from an introduction to welding, through critical safety information, to details of specific welding and cutting processes, and on to the related areas of shop math, welding metallurgy, weldability of metals, reading technical drawings, fabrication, testing and inspection of welds, welding joint design, welding costs, welding symbols, and AWS SENSE certification.

Each section of the text introducing a welding process or processes begins with an introduction to the equipment and materials to be used in the process(es), including setup in preparation for welding. The remaining chapters for the specific process concentrate on the actual welding techniques in various applications and positions. The content progresses from basic concepts to the more complex welding technology. Once this technology is understood, the student is able to quickly master new welding tasks or processes. All of the welding technology and practices lead the student toward the ability to take and pass an AWS SENSE certification workmanship standard.

The sections on welding processes are laid out so that they can be studied individually and in any order. This was done so students can study the process or processes that might relate to their job requirements. However, students are encouraged to study and learn all of the processes so they have the broadest possible future job opportunities.

Objectives listed at the beginning of each chapter tell the student and instructor what is to be learned while studying the chapter. A survey of the objectives will show that the student will have the opportunity to develop a full range of welding skills. Each major process is presented independently so that the instructor can include or exclude them to better meet the needs of the local area served by the program. However, the student can still learn all essential information needed for a thorough understanding of all processes studied.

Key Terms are listed at the beginning of the chapter. These key terms are **boldface** and defined throughout the chapters so students will recognize them as they appear. Terms and definitions used throughout the text are based on the American Welding Society's standards. Industry jargon has also been included when appropriate.

Cautions for the student are given throughout the text and point out potential safety concerns or give additional specific information that will make working safer.

Think Green text boxes contain information on conserving materials, energy, and other natural resources and ways to avoid potential environmental contamination.

Metric equivalents are listed in parentheses for dimensions. When the standard unit is an approximation, the metric equivalent has been rounded to the nearest whole number; however, when the standard unit is an exact value, the metric conversions are more precise.

Illustrations consist of figures, tables, and graphs. Figures include both photographs and line art. Numerous figures contain close-up full-color photos of actual welding, and others show welding products and equipment. The colorful detailed figure line art is used extensively throughout the text to help illustrate concepts and clarify the material. Tables and graphs contain valuable technical information on materials, equipment setup, and welding process parameters. They are designed to help the student in class and later serve as an on-the-job reference.

Experiments and Practices are learning activities that are presented in most of the chapters. The end of each experiment is identified by the (◆) symbol and the end of each practice is identified by the (◆) symbol.

Experiments help the student learn the parameters of each welding process. Often, because it is hard to perform the experiment and to observe the results closely, students may do most of the experiments in a small group. In the experiments, students change the parameters to observe the effect on the process. In this way, students learn to manipulate the variables to obtain the desired welding outcome for given conditions. The experiments provided in the chapters do not have right or wrong answers. They are designed to allow the student to learn the operating limitations or the effects of changes that may occur during the welding process.

Practices are included to enable the student to develop the required manipulative skills using different materials and material thicknesses in different positions for each process. A sufficient number of practices is provided so that, after the basics are learned, the student may choose an area of specialization. Materials specified in the practices may be varied in both thickness and length to accommodate those supplies that students have in their lab. Changes within a limited range of both thickness and length will not affect the learning process designed for the practice.

Mechanical drawings are included with many of the welding practices. These drawings are included to help students better understand mechanical drawings and to show them how the metal is assembled. Most of the drawings are laid out in third-angle projection format, some are in the first-angle projection format, and a few are laid out with the side view shown in an alternate position. The third-angle projection format has been the standard used in the United States for years. However, because of the increasing interaction with the world economy, and because of the fact that many other countries use the first-angle projection format, it has been included. All three drawing formats are commonly used and are included. Items not normally included on true mechanical drawings such as the weld, torch, or electrode, and filler metal have been included to aid in students' understanding of the drawings.

Summaries at the end of each chapter recap the significant material covered in the chapter. This summary will help the student more completely understand the chapter material and will serve as a handy study tool.

Review questions at the end of each chapter can be used as indicators of how well the student has learned the material in each chapter.

Glossary definitions include the key terms listed at the beginning of each chapter and also other relevant welding terms. Included in the Glossary are bilingual terms in Spanish. Many definitions feature additional drawings to assist students in gaining a complete understanding of the terms.

What's New in the 8th Edition

This eight edition of *Welding: Principles and Applications* has been thoroughly revised and reorganized to reflect the latest welding technologies. Changes include the following:

- New chapters include "SMAW SENSE Certification," "GMAW and FCAW SENSE Certification," and "GTAW SENSE Certification"
- New welding processes and technologies such as magnetic pulse welding
- Expanded material on processes such as plasma cutting, FCAW, GMAW, and others
- New feature stories at the end in many of the chapters
- New and updated illustrations and photographs in every chapter

The use of new, full-color, detailed close-up photographs and detailed colored line art makes it much easier for the student to see what is expected to produce a quality weld.

Supplements

Study Guide/Lab Manual

The *Study Guide/Lab Manual* has been updated to reflect changes made to the eighth edition. The *Study Guide/Lab Manual* is designed to reinforce student understanding of the concepts presented in the text. Each chapter starts with a review of the important topics discussed in the chapter. Students can then test their knowledge by answering additional questions. Lab exercises are included in those chapters (as appropriate) to reinforce the primary objectives of the lesson. Artwork and safety precautions are included throughout the manual.

Instructor Companion Website

The Instructor Companion Website, found on cengagebrain.com, includes the following components to help minimize instructor preparation time and engage students:

- **PowerPoint**® lecture slides, which present the highlights of each chapter.
- An **Image Gallery**, which offers a database of hundreds of images in the text. These can easily be imported into the PowerPoint® presentations.

- An **Answer Key** file, which provides the answers to all end-of-chapter questions and the quizzes found in the Study Guide/Lab Manual.

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- Author, edit, and manage test bank content from multiple Cengage Learning solutions.
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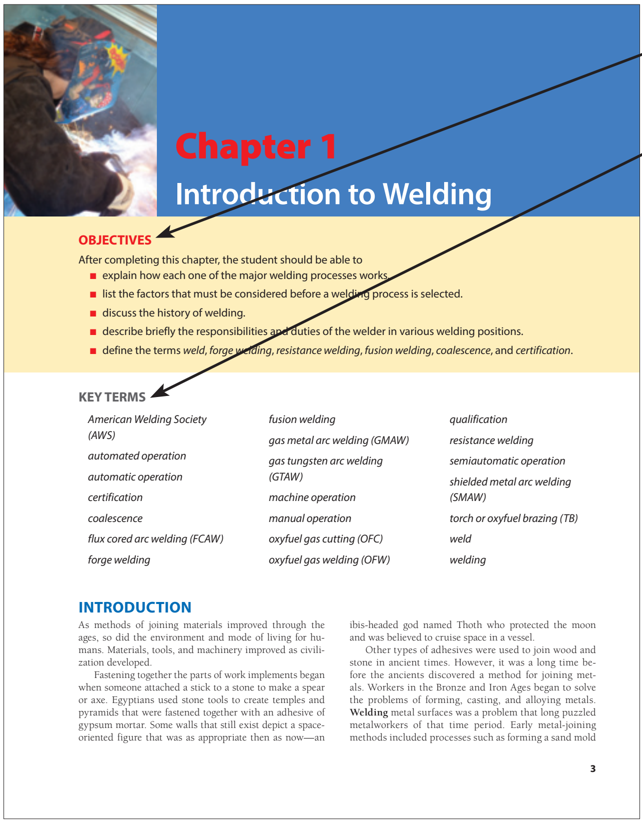
MINDTAP Welding for Welding: Principles and Applications

MindTap is a personalized teaching experience with relevant assignments that guide students to analyze, apply, and improve thinking, allowing you to measure skills and outcomes with ease.

- *Personalize Teaching*: Becomes YOURS with a Learning Path that is built with key student objectives. Control what your students see and when they see it—match your syllabus exactly by hiding, rearranging, or adding your own content.
- *Guide Students*: Goes beyond the traditional "lift and shift" model by creating a unique learning path of relevant readings, multimedia, and activities that move students up the learning taxonomy from basic knowledge and comprehension to analysis and application.
- *Measure Skills and Outcomes*: Analytics and reports provide a snapshot of class progress, time on task, engagement, and completion rates.

FEATURES OF THE TEXT



Chapter 1
Introduction to Welding

OBJECTIVES

After completing this chapter, the student should be able to

- explain how each one of the major welding processes works.
- list the factors that must be considered before a welding process is selected.
- discuss the history of welding.
- describe briefly the responsibilities and duties of the welder in various welding positions.
- define the terms *weld, forge welding, resistance welding, fusion welding, coalescence,* and *certification.*

KEY TERMS

American Welding Society (AWS), *automated operation*, *automatic operation*, *certification*, *coalescence*, *flux cored arc welding (FCAW)*, *forge welding*, *fusion welding*, *gas metal arc welding (GMAW)*, *gas tungsten arc welding (GTAW)*, *machine operation*, *manual operation*, *oxyfuel gas cutting (OFC)*, *oxyfuel gas welding (OFW)*, *qualification*, *resistance welding*, *semiautomatic operation*, *shielded metal arc welding (SMAW)*, *torch or oxyfuel brazing (TB)*, *weld*, *welding*

INTRODUCTION

As methods of joining materials improved through the ages, so did the environment and mode of living for humans. Materials, tools, and machinery improved as civilization developed.

Fastening together the parts of work implements began when someone attached a stick to a stone to make a spear or axe. Egyptians used stone tools to create temples and pyramids that were fastened together with an adhesive of gypsum mortar. Some walls that still exist depict a space-oriented figure that was as appropriate then as now—an ibis-headed god named Thoth who protected the moon and was believed to cruise space in a vessel.

Other types of adhesives were used to join wood and stone in ancient times. However, it was a long time before the ancients discovered a method for joining metals. Workers in the Bronze and Iron Ages began to solve the problems of forming, casting, and alloying metals. **Welding** metal surfaces was a problem that long puzzled metalworkers of that time period. Early metal-joining methods included processes such as forming a sand mold

3

Objectives, found at the beginning of each chapter, are a brief list of the most important topics to study in the chapter.

Key Terms are the most important technical words you will learn in the chapter. These are listed at the beginning of each chapter following the Objectives and appear in **color print** where they are first defined. These terms are also defined in the Glossary at the end of the book.

Cautions summarize critical safety rules. They alert you to operations that could hurt you or someone else. They are not only covered in the safety chapter but also found throughout the text when they apply to the discussion, practice, or experiment.

Think Green boxes contain information on conserving materials, energy, and other natural resources and ways to avoid potential environmental contamination.

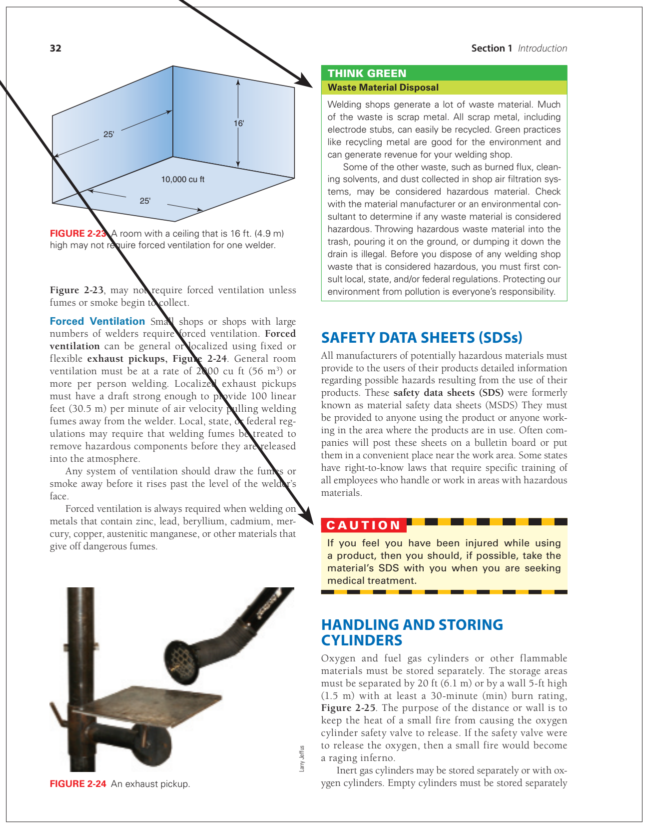


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FIGURE 2-23 A room with a ceiling that is 16 ft. (4.9 m) high may not require forced ventilation for one welder.

Figure 2-23, may not require forced ventilation unless fumes or smoke begin to collect.

Forced Ventilation Small shops or shops with large numbers of welders require forced ventilation. **Forced ventilation** can be general or localized using fixed or flexible **exhaust pickups, Figure 2-24**. General room ventilation must be at a rate of 2000 cu ft (56 m³) or more per person welding. Localized exhaust pickups must have a draft strong enough to provide 100 linear feet (30.5 m) per minute of air velocity pulling welding fumes away from the welder. Local, state, or federal regulations may require that welding fumes be treated to remove hazardous components before they are released into the atmosphere.

Any system of ventilation should draw the fumes or smoke away before it rises past the level of the welder's face.

Forced ventilation is always required when welding on metals that contain zinc, lead, beryllium, cadmium, mercury, copper, austenitic manganese, or other materials that give off dangerous fumes.

FIGURE 2-24 An exhaust pickup.

THINK GREEN
Waste Material Disposal

Welding shops generate a lot of waste material. Much of the waste is scrap metal. All scrap metal, including electrode stubs, can easily be recycled. Green practices like recycling metal are good for the environment and can generate revenue for your welding shop.

Some of the other waste, such as burned flux, cleaning solvents, and dust collected in shop air filtration systems, may be considered hazardous material. Check with the material manufacturer or an environmental consultant to determine if any waste material is considered hazardous. Throwing hazardous waste material into the trash, pouring it on the ground, or dumping it down the drain is illegal. Before you dispose of any welding shop waste that is considered hazardous, you must first consult local, state, and/or federal regulations. Protecting our environment from pollution is everyone's responsibility.

SAFETY DATA SHEETS (SDSs)

All manufacturers of potentially hazardous materials must provide to the users of their products detailed information regarding possible hazards resulting from the use of their products. These **safety data sheets (SDS)** were formerly known as material safety data sheets (MSDS) They must be provided to anyone using the product or anyone working in the area where the products are in use. Often companies will post these sheets on a bulletin board or put them in a convenient place near the work area. Some states have right-to-know laws that require specific training of all employees who handle or work in areas with hazardous materials.

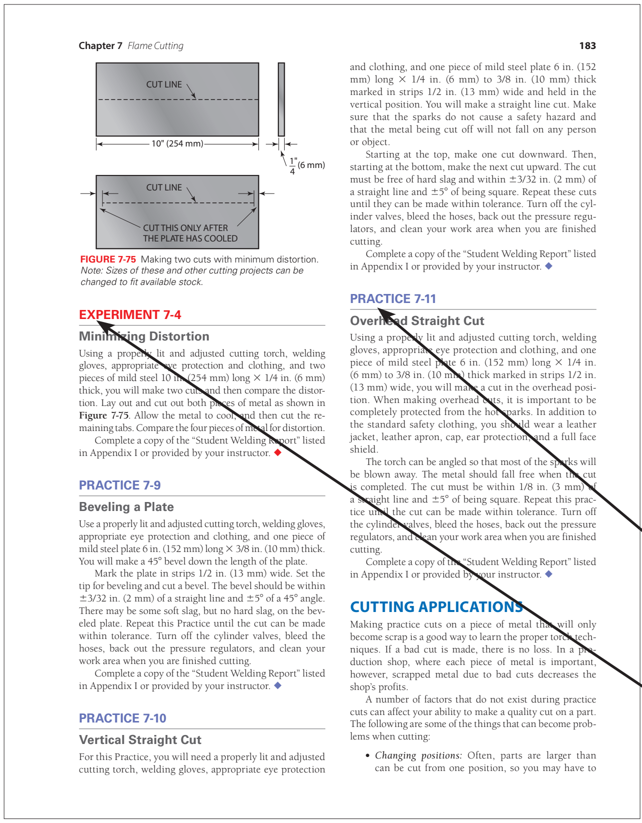
CAUTION

If you feel you have been injured while using a product, then you should, if possible, take the material's SDS with you when you are seeking medical treatment.

HANDLING AND STORING CYLINDERS

Oxygen and fuel gas cylinders or other flammable materials must be stored separately. The storage areas must be separated by 20 ft (6.1 m) or by a wall 5-ft high (1.5 m) with at least a 30-minute (min) burn rating, **Figure 2-25**. The purpose of the distance or wall is to keep the heat of a small fire from causing the oxygen cylinder safety valve to release. If the safety valve were to release the oxygen, then a small fire would become a raging inferno.

Inert gas cylinders may be stored separately or with oxygen cylinders. Empty cylinders must be stored separately



Chapter 7 *Flame Cutting* 183

FIGURE 7-75 Making two cuts with minimum distortion. *Note: Sizes of these and other cutting projects can be changed to fit available stock.*

EXPERIMENT 7-4

Minimizing Distortion

Using a properly lit and adjusted cutting torch, welding gloves, appropriate eye protection and clothing, and two pieces of mild steel 10 in. (254 mm) long × 1/4 in. (6 mm) thick, you will make two cuts and then compare the distortion. Lay out and cut out both pieces of metal as shown in **Figure 7-75**. Allow the metal to cool, and then cut the remaining tabs. Compare the four pieces of metal for distortion.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ♦

PRACTICE 7-9

Beveling a Plate

Use a properly lit and adjusted cutting torch, welding gloves, appropriate eye protection and clothing, and one piece of mild steel plate 6 in. (152 mm) long × 3/8 in. (10 mm) thick. You will make a 45° bevel down the length of the plate.

Mark the plate in strips 1/2 in. (13 mm) wide. Set the tip for beveling and cut a bevel. The bevel should be within ±3/32 in. (2 mm) of a straight line and ±5° of a 45° angle. There may be some soft slag, but no hard slag, on the beveled plate. Repeat this Practice until the cut can be made within tolerance. Turn off the cylinder valves, bleed the hoses, back out the pressure regulators, and clean your work area when you are finished cutting.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ♦

PRACTICE 7-10

Vertical Straight Cut

For this Practice, you will need a properly lit and adjusted cutting torch, welding gloves, appropriate eye protection and clothing, and one piece of mild steel plate 6 in. (152 mm) long × 1/4 in. (6 mm) to 3/8 in. (10 mm) thick marked in strips 1/2 in. (13 mm) wide and held in the vertical position. You will make a straight line cut. Make sure that the sparks do not cause a safety hazard and that the metal being cut off will not fall on any person or object.

Starting at the top, make one cut downward. Then, starting at the bottom, make the next cut upward. The cut must be free of hard slag and within ±3/32 in. (2 mm) of a straight line and ±5° of being square. Repeat these cuts until they can be made within tolerance. Turn off the cylinder valves, bleed the hoses, back out the pressure regulators, and clean your work area when you are finished cutting.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ♦

PRACTICE 7-11

Overhead Straight Cut

Using a properly lit and adjusted cutting torch, welding gloves, appropriate eye protection and clothing, and one piece of mild steel plate 6 in. (152 mm) long × 1/4 in. (6 mm) to 3/8 in. (10 mm) thick marked in strips 1/2 in. (13 mm) wide, you will make a cut in the overhead position. When making overhead cuts, it is important to be completely protected from the hot sparks. In addition to the standard safety clothing, you should wear a leather jacket, leather apron, cap, ear protection, and a full face shield.

The torch can be angled so that most of the sparks will be blown away. The metal should fall free when the cut is completed. The cut must be within 1/8 in. (3 mm) of a straight line and ±5° of being square. Repeat this practice until the cut can be made within tolerance. Turn off the cylinder valves, bleed the hoses, back out the pressure regulators, and clean your work area when you are finished cutting.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ♦

CUTTING APPLICATIONS

Making practice cuts on a piece of metal that will only become scrap is a good way to learn the proper torch techniques. If a bad cut is made, there is no loss. In a production shop, where each piece of metal is important, however, scrapped metal due to bad cuts decreases the shop's profits.

A number of factors that do not exist during practice cuts can affect your ability to make a quality cut on a part. The following are some of the things that can become problems when cutting:

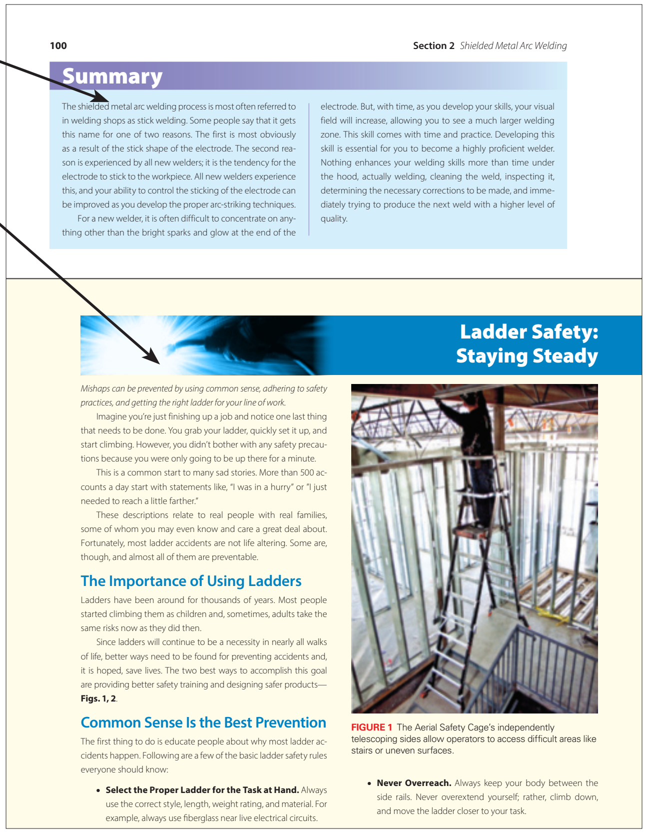
- *Changing positions:* Often, parts are larger than can be cut from one position, so you may have to

Practices are hands-on exercises designed to build your welding skills. Each practice describes in detail what skill you will learn and what equipment, supplies, and tools you will need to complete the exercise.

Experiments are designed to allow you to see what effect changes in the process settings, operation, or techniques have on the type of weld produced. Many are group activities and will help you learn as a team.

Summaries review the important points in the chapter and serve as a useful study tool.

Real-World Features at the end of all chapters present a story that describes a real-world application of the theory learned in the chapter. You will see how particular knowledge and skills are important to the world.



100 Section 2 *Shielded Metal Arc Welding*

Summary

The shielded metal arc welding process is most often referred to in welding shops as stick welding. Some people say that it gets this name for one of two reasons. The first is most obviously as a result of the stick shape of the electrode. The second reason is experienced by all new welders; it is the tendency for the electrode to stick to the workpiece. All new welders experience this, and your ability to control the sticking of the electrode can be improved as you develop the proper arc-striking techniques.

For a new welder, it is often difficult to concentrate on anything other than the bright sparks and glow at the end of the electrode. But, with time, as you develop your skills, your visual field will increase, allowing you to see a much larger welding zone. This skill comes with time and practice. Developing this skill is essential for you to become a highly proficient welder. Nothing enhances your welding skills more than time under the hood, actually welding, cleaning the weld, inspecting it, determining the necessary corrections to be made, and immediately trying to produce the next weld with a higher level of quality.

Ladder Safety: Staying Steady

Mishaps can be prevented by using common sense, adhering to safety practices, and getting the right ladder for your line of work.

Imagine you're just finishing up a job and notice one last thing that needs to be done. You grab your ladder, quickly set it up, and start climbing. However, you didn't bother with any safety precautions because you were only going to be up there for a minute.

This is a common start to many sad stories. More than 500 accounts a day start with statements like, "I was in a hurry" or "I just needed to reach a little farther."

These descriptions relate to real people with real families, some of whom you may even know and care a great deal about. Fortunately, most ladder accidents are not life altering. Some are, though, and almost all of them are preventable.

The Importance of Using Ladders

Ladders have been around for thousands of years. Most people started climbing them as children and, sometimes, adults take the same risks now as they did then.

Since ladders will continue to be a necessity in nearly all walks of life, better ways need to be found for preventing accidents and, it is hoped, save lives. The two best ways to accomplish this goal are providing better safety training and designing safer products—**Figs. 1, 2**.

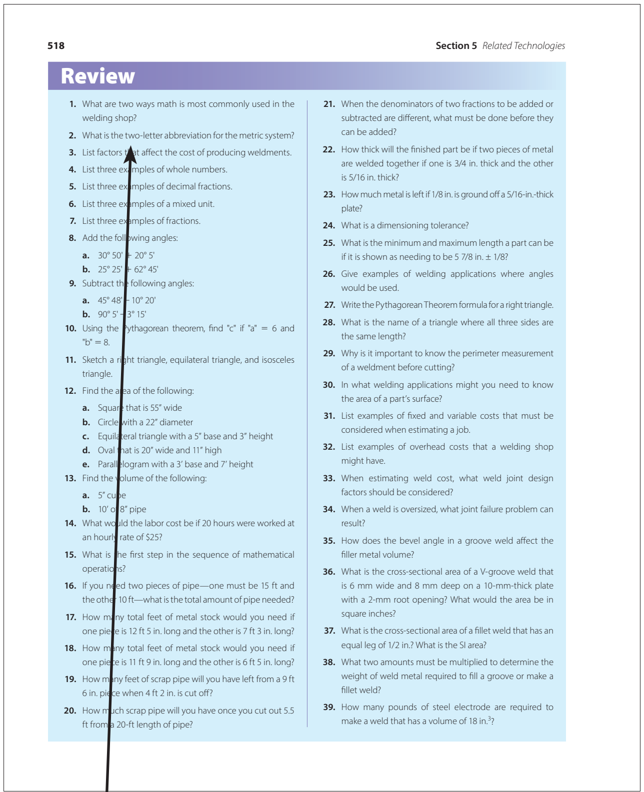
Common Sense Is the Best Prevention

The first thing to do is educate people about why most ladder accidents happen. Following are a few of the basic ladder safety rules everyone should know:

- **Select the Proper Ladder for the Task at Hand.** Always use the correct style, length, weight rating, and material. For example, always use fiberglass near live electrical circuits.

FIGURE 1 The Aerial Safety Cage's independently telescoping sides allow operators to access difficult areas like stairs or uneven surfaces.

- **Never Overreach.** Always keep your body between the side rails. Never overextend yourself; rather, climb down, and move the ladder closer to your task.



518 Section 5 *Related Technologies*

Review

1. What are two ways math is most commonly used in the welding shop?
2. What is the two-letter abbreviation for the metric system?
3. List factors that affect the cost of producing weldments.
4. List three examples of whole numbers.
5. List three examples of decimal fractions.
6. List three examples of a mixed unit.
7. List three examples of fractions.
8. Add the following angles:
   a. 30° 50′ + 20° 5′
   b. 25° 25′ + 62° 45′
9. Subtract the following angles:
   a. 45° 48′ − 10° 20′
   b. 90° 5′ − 3° 15′
10. Using the Pythagorean theorem, find "c" if "a" = 6 and "b" = 8.
11. Sketch a right triangle, equilateral triangle, and isosceles triangle.
12. Find the area of the following:
    a. Square that is 55″ wide
    b. Circle with a 22″ diameter
    c. Equilateral triangle with a 5″ base and 3″ height
    d. Oval that is 20″ wide and 11″ high
    e. Parallelogram with a 3′ base and 7′ height
13. Find the volume of the following:
    a. 5″ cube
    b. 10′ of 8″ pipe
14. What would the labor cost be if 20 hours were worked at an hourly rate of $25?
15. What is the first step in the sequence of mathematical operations?
16. If you need two pieces of pipe—one must be 15 ft and the other 10 ft—what is the total amount of pipe needed?
17. How many total feet of metal stock would you need if one piece is 12 ft 5 in. long and the other is 7 ft 3 in. long?
18. How many total feet of metal stock would you need if one piece is 11 ft 9 in. long and the other is 6 ft 5 in. long?
19. How many feet of scrap pipe will you have left from a 9 ft 6 in. piece when 4 ft 2 in. is cut off?
20. How much scrap pipe will you have once you cut out 5.5 ft from a 20-ft length of pipe?
21. When the denominators of two fractions to be added or subtracted are different, what must be done before they can be added?
22. How thick will the finished part be if two pieces of metal are welded together if one is 3/4 in. thick and the other is 5/16 in. thick?
23. How much metal is left if 1/8 in. is ground off a 5/16-in.-thick plate?
24. What is a dimensioning tolerance?
25. What is the minimum and maximum length a part can be if it is shown as needing to be 5 7/8 in. ± 1/8?
26. Give examples of welding applications where angles would be used.
27. Write the Pythagorean Theorem formula for a right triangle.
28. What is the name of a triangle where all three sides are the same length?
29. Why is it important to know the perimeter measurement of a weldment before cutting?
30. In what welding applications might you need to know the area of a part's surface?
31. List examples of fixed and variable costs that must be considered when estimating a job.
32. List examples of overhead costs that a welding shop might have.
33. When estimating weld cost, what weld joint design factors should be considered?
34. When a weld is oversized, what joint failure problem can result?
35. How does the bevel angle in a groove weld affect the filler metal volume?
36. What is the cross-sectional area of a V-groove weld that is 6 mm wide and 8 mm deep on a 10-mm-thick plate with a 2-mm root opening? What would the area be in square inches?
37. What is the cross-sectional area of a fillet weld that has an equal leg of 1/2 in.? What is the SI area?
38. What two amounts must be multiplied to determine the weight of weld metal required to fill a groove or make a fillet weld?
39. How many pounds of steel electrode are required to make a weld that has a volume of 18 in.^{3}?

Review questions help measure the skills and knowledge you learned in the chapter. Each question is designed to help you apply and understand the information in the chapter.

Success Stories are found at the beginning of each of the seven sections in the text. These stories are about real people who have become successful by using their welding skills. Each story is different, but one message is repeated by all story contributors: welding can be a rich and rewarding career.

Success Story

My name is Shakirah Harrell. I was born in Newark, New Jersey and raised in the little town of Powellsville, North Carolina. I graduated from Hertford County High School in Ahoskie, North Carolina. As a single young parent, I needed to find a career field that would support my family, so I moved to Hampton, Virginia. I started my welding career at the age of 23.

At that time, the only thing I knew about welding was that it was a good paying job. I applied at Northrop Grumman, a shipyard in Newport News, Virginia, and began my training as a welder. To help support my family, I worked as a grocery store manager in the morning and welder at night. After one year in the field as a 3rd class welder, I got accepted into the apprenticeship program. I spent the next five years learning the welding trade while still being able to support my family. I graduated from the apprenticeship program in 2008.

Then I decided to pursue another angle in the welding trade. I got hired at a local welding school where I began instructing basic welding during the day while working on my Bachelor's Degree in business management at night and online. After only a few months, I was asked to take a position at the school as the welding coordinator for the entire program.

After four years, I missed welding and the money I would make, so I decided to go back into the field as a contractor at another local shipyard in Norfolk, Virginia. Over the next few years, I followed welding opportunities across other parts of the United States. I was a structural welder at an ethanol plant project in Liberal, Kansas. Following that, I moved to Freeport, Texas, took a refresher pipe welding course offered by Fluor, and started working on a chemical plant project for Dow Chemical Company.

After being away from Virginia for so many years, I was homesick and decided to go back to Virginia; but as a result of the downturn in the economy, I was not able to find a good high-paying job, so I moved back to Texas. I am currently a welding instructor at Tulsa Welding School and Technology Center at the Houston campus.

Welding has been a great career for me and a skill that has provided for my family. My oldest son has joined the United States Navy, one of the others is a high school senior, and the youngest is a high school junior. I'm proud to be a welder, I'm proud of my kids, and proud of the life that welding has provided for us.

Bilingual Glossary definitions provide a Spanish equivalent for each new term. Additional line art in the Glossary will also help you gain a greater understanding of challenging terms.

Acknowledgments

To bring a book of this size to publication requires the assistance of many individuals, and the author and publisher thank the following for their unique contributions to this and/or prior editions:

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from years of experience in welding and teaching, but most of all for their friendship.

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- In memory of Leo Taylor, an outstanding welder educator and welder who trained many young people in the art and skill of welding.
- Sam Burris, for his expertise in computer graphics that helped make the illustrations and photographs dynamic.
- To my wife, Carol, for all of her moral support, and to my daughters, Wendy and Amy, for all of the general office help they provided.

About the Author

In 1965, during my senior year at New Bern High School in North Carolina, while taking shop classes, I am proud to say I joined the Vocational Industrial Clubs of America (VICA), now SkillsUSA-VICA. SkillsUSA brings together educators, administrators, corporate America, labor organizations, trade associations, and government in a coordinated effort to address America's need for a globally competitive, skilled workforce. The mission of SkillsUSA is to help our students become world-class workers and responsible American citizens. Through my involvement in SkillsUSA, I learned a great deal about industry and business. In SkillsUSA I learned the value of integrity, responsibility, citizenship, service, and respect. In addition, I developed leadership skills, established goals, and learned the value of performing quality work. These are all things that I still use in my life today.

During my junior year of high school, I learned to weld in metal shop. I was taught basic welding principles and applications, and I was able to build a number of projects in shop using oxyacetylene welding, shielded metal arc welding, twin carbon arc welding, and torch brazing.

The practice welds helped me develop welding skills, and building the projects allowed me to start developing some fabrication skills. By the end of my junior year, I had become a fairly skilled welder.

In my senior year I was given an opportunity to join Mr. Z. T. Koonce's first class in a new program called Industrial Cooperative Training (ICT). ICT is a cooperative work experience program that coordinates school experiences with real jobs. This allowed me to attend high school in the morning, where I completed my required English, math, and other academic courses for graduation. In my ICT class we were taught skills that would help us get a job—such as how to fill out a job application, how to interview, and so on. In the afternoons I worked as a welder. After graduation, I started a full-time job as a welder at Barbour Boat Works, where I refined my welding skills and was allowed to work with the other welders in the shipyard. My first welding assignment was on a barge making intermittent welds to attach the deck to the barge's ribs.

As my welding skills improved, my supervisor allowed me to apply my new welding skills to more difficult jobs. I welded on barges, military landing crafts, tugboats, PT boats, small tankers, and other marine vessels. This is how I earned money toward my college education.

With my welding skills, I was able to get a job in a small welding shop in Madisonville, Tennessee and attended Hiwassee College. After graduating from Hiwassee, I found other welding jobs that allowed me to continue my education at the University of Tennessee, where I earned a bachelor's degree. After four years, I had both a college degree and four years of welding experience, which together qualified me for my job as a vocational teacher.

During my career as a welder, I have welded on tanks, pressure vessels, oil well drilling equipment, farm equipment, buildings, racecars, aircraft, piping systems,

and more. As a vocational teacher, I have taught in high schools, schools for special education, schools for the deaf, three colleges, and numerous industrial shops. I have also been a consultant to the welding industry and a resource for students, educators, and school administrators.

Larry Jeffus has more than 50 years of welding experience and more than 40 years of experience as a classroom teacher. He is the author of several Delmar Cengage Learning welding publications. Prior to retiring from teaching, Professor Jeffus taught at Eastfield College, part of the Dallas County Community College District. Since retiring from full-time teaching, he remains very active in the welding community, especially in the field of education. He serves on several welding program technical advisory committees and has visited high schools, colleges, universities, and technical campuses in more than 40 states and four foreign countries. Professor Jeffus was selected as Outstanding Postsecondary Technical Educator in the State of Texas by the Texas Technical Society. He holds a bachelor of science degree and has completed postgraduate studies.

Professor Jeffus has served for 12 years as a board member on the Texas Workforce Investment Council in the Texas Governor's office, where he works to develop a skilled workforce and bring economic development to the state. He served as a member of the Apprenticeship Project Leadership Team, where he helped establish apprenticeship training programs for the State of Texas, and he has made numerous trips to Washington, DC, to lobby for vocational and technical education.

He has been actively involved in the American Welding Society for more than 40 years, and has served on the General Education Committee and as the chairman of the North Texas Section of the American Welding Society. He is a Life Member of the American Welding Society.

Index of Experiments and Practices

The following Experiments and Practices are listed in the order in which they appear in the chapter. It should be noted that not all chapters have Experiments and Practices.

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Chapter 8

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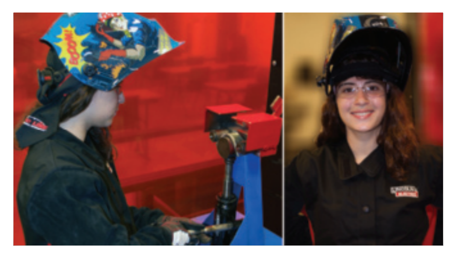
Section 1

Introduction

Success Story



My name is Erin Boren and I'm 21. I first learned to weld while in high school at Lakeview Centennial High School in Garland, Texas. My welding instructor was Mr. Jim Barnett. He taught me the basics of all of the welding processes. My favorite welding process was and still is GMAW. While in high school I passed the 1/2 in. thick open root V-groove guided bend test with the GMAW process.

In addition to making practice welds on a variety of different types of metals and metal thicknesses with all of the different welding processes, Mr. Barnett had us fabricate welding projects. I made a vase, picture frame, and some other projects. My favorite project was when Mr. Barnett let me program the plasma cutter to cut out my name and a silhouette of my favorite animal. He then let me gas weld all of it together to make a nameplate. I loved being able to make these welded projects. It was really fun cutting out the parts and fitting them together so I could weld them up.

Of all my high school courses I loved my welding classes most. Welding classes gave me a chance to learn a skill that I have truly enjoyed.

I have always loved the water. My life goal is to become an underwater welder, so I took classes to become certified as a scuba diver. In addition I worked at Surf and Swim during the summers. Not all of my time was spent as fun in the sun; I used the flux core process to build a long section of security fence. The fence owner said she "loved it" which made me feel proud of my work.

I'm currently enrolled in welding classes at Eastfield College in Mesquite, Texas. My first welding class was a welding 6-week survey course that covered all of the welding processes. Currently my welding instructor is Mr. Jeff Mitchell. He helped me develop my welding skills, and I passed the 4G (overhead) open root V-groove bend test in 3/8 in. plate with the shielded metal arc welding process.

My next class will be the AWS SENSE Level I certification. Mr. Mitchell feels I'm ready to pass both the workmanship qualification test and the V-groove certification. I'm looking forward to the challenge.

One of the highlights of my welding career was being asked by Mr. Mitchell to help Larry Jeffus take the cover photo for this textbook. I'm sure with all of my welding equipment and PPE on you might not recognize me, but I know it's me and that's good enough.

Erin's high school teacher, Mr. Barnett said, "There's no greater thrill than having a student like Erin become a successful welder." Her college professor Mr. Mitchell said, "Erin's great work ethic, positive can-do attitude, and friendly personality have equipped her very well. With her outstanding welding skills, I expect her to be very successful in the future."

Chapter 1
Introduction to Welding

OBJECTIVES

After completing this chapter, the student should be able to

- explain how each one of the major welding processes works.
- list the factors that must be considered before a welding process is selected.
- discuss the history of welding.
- describe briefly the responsibilities and duties of the welder in various welding positions.
- define the terms *weld*, *forge welding*, *resistance welding*, *fusion welding*, *coalescence*, and *certification*.

KEY TERMS

American Welding Society (AWS)
automated operation
automatic operation
certification
coalescence
flux cored arc welding (FCAW)
forge welding
fusion welding
gas metal arc welding (GMAW)
gas tungsten arc welding (GTAW)
machine operation
manual operation
oxyfuel gas cutting (OFC)
oxyfuel gas welding (OFW)
qualification
resistance welding
semiautomatic operation
shielded metal arc welding (SMAW)
torch or oxyfuel brazing (TB)
weld
welding

INTRODUCTION

As methods of joining materials improved through the ages, so did the environment and mode of living for humans. Materials, tools, and machinery improved as civilization developed.

Fastening together the parts of work implements began when someone attached a stick to a stone to make a spear or axe. Egyptians used stone tools to create temples and pyramids that were fastened together with an adhesive of gypsum mortar. Some walls that still exist depict a space-oriented figure that was as appropriate then as now—an ibis-headed god named Thoth who protected the moon and was believed to cruise space in a vessel.

Other types of adhesives were used to join wood and stone in ancient times. However, it was a long time before the ancients discovered a method for joining metals. Workers in the Bronze and Iron Ages began to solve the problems of forming, casting, and alloying metals. **Welding** metal surfaces was a problem that long puzzled metalworkers of that time period. Early metal-joining methods included processes such as forming a sand mold

on top of a piece of metal and casting the desired shape directly on the base metal so that both parts fused together, forming a single piece of metal, **Figure 1-1**. Another metal-joining method used in early years was to place two pieces of metal close together and pour molten metal between them. When the edges of the base metal melted, the flow of metal was then dammed up and allowed to harden, **Figure 1-2**.

This bronze goat statue at the Qingyang Taoist Temple in Chengdu, China was cast more than 1500 years ago and repaired with braze welding approximately 1000 years ago, **Figure 1-3**.

The Industrial Revolution, from 1750 to 1850, introduced a method of joining pieces of iron together known as **forge welding** or hammer welding. This process involved the use of a forge to heat the metal to a soft, plastic temperature. The ends of the iron were then placed together and hammered until fusion took place.

Forge welding remained as the primary welding method until Elihu Thomson, in the year 1886, developed the **resistance welding** technique. This technique provided a more reliable and faster way of joining metal than did previous methods.

As techniques were further developed, riveting was replaced in the United States and Europe by **fusion welding**. At that time the welding process was considered to be vital to military security. Welding repairs to the ships damaged during World War I were done in great secrecy. Even today some aspects of welding are closely guarded secrets.

Since the end of World War I, many welding methods have been developed for joining metals. These various welding methods play an important role in the expansion and production of the welding industry. Welding has become a dependable, efficient, and economical method for joining metal.

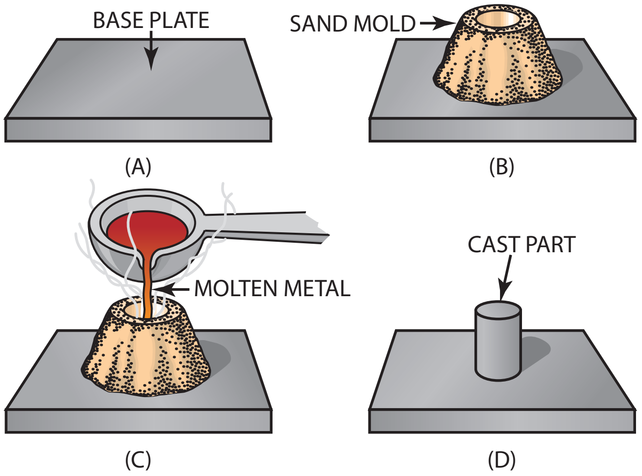


FIGURE 1-1 Direct casting: (A) base plate to have part cast on it, (B) sand molded into shape desired, (C) pouring hot metal into mold, and (D) part cast is now part of the base plate.

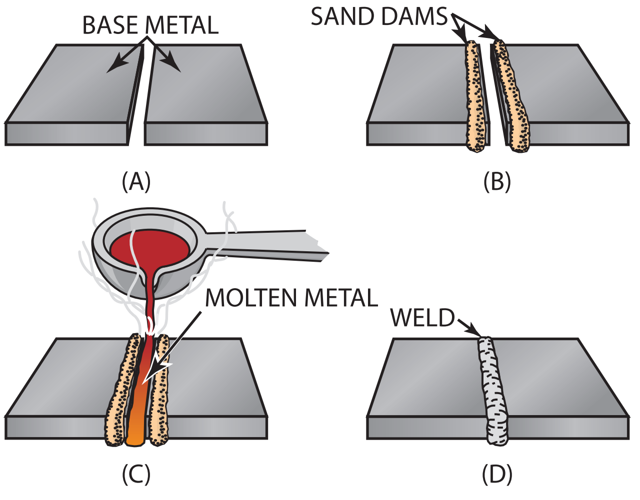


FIGURE 1-2 Flow welding: (A) two pieces of metal plate, (B) sand dams to hold molten metal in place, (C) molten metal poured between metal plates, and (D) finished welded plate.

Larry Jeffus

FIGURE 1-3 Bronze goat statue in Chengdu, China cast more than 1,500 years ago and repaired with braze welding about 1,000 years ago.

Welding Terminology

The use of regional terms by skilled workers is a common practice in all trade areas, including welding. As an example, oxyacetylene welding is one part of the larger group of processes known as **oxyfuel gas welding (OFW)**. Some of the names used to refer to oxyacetylene welding (OAW) include *gas welding* and *torch welding*. **Shielded metal arc welding (SMAW)** is often called *stick welding*, *rod welding*, or just *welding*. As you begin your work career you will learn the various names used in your area, but you should always keep in mind and use the more formal terms whenever possible.

WELDING DEFINED

A **weld** is defined by the American Welding Society (AWS) as "a localized **coalescence** (the fusion or growing together of the grain structure of the materials being welded) of metals or nonmetals produced either by heating the materials to the required welding temperatures, with or without the application of pressure, or by the application of pressure alone, and with or without the use of filler materials." **Welding** is defined as "a joining process that produces coalescence of materials by heating them to the welding temperature, with or without the application of pressure or by the application of pressure alone, and with or without the use of filler metal." In less technical language, a weld is made when separate pieces of material to be joined combine and form one piece when

- enough heat is applied to raise the temperature high enough to cause softening or melting and the pieces flow together,
- enough pressure is used to force the pieces together so that the surfaces coalesce, or
- enough heat and pressure are used together to force the separate pieces of material to combine and form one piece.

A filler material may or may not be added to the joint to form a completed weld joint. It is also important to note that the word *material* is used because today welds can be made from a growing list of materials such as plastic, glass, and ceramics.

USES OF WELDING

Modern welding techniques are used in the construction of numerous products, **Figure 1-4** and **Figure 1-5**. Ships, buildings, bridges, and recreational rides are fabricated by welding processes. Welding is often used to produce the machines that are used to manufacture new products.


NASA

FIGURE 1-4 Space shuttle being made ready for its launch into space. Notice the large welded support structure used to prepare the shuttle for launch.

Welding has made it possible for airplane manufacturers to meet the design demands of strength-to-weight ratios for both commercial and military aircraft.

The exploration of space would not be possible without modern welding techniques. From the very beginning of early rockets to today's aerospace industry, welding has played an important role. The space shuttle's construction required the improvement of welding processes. Many of these improvements have helped improve our daily lives.

Welding, brazing, and cutting experiments were conducted aboard the Skylab from May 1973 to February 1974. Today welding, brazing, and cutting experiments are often conducted aboard the International Space Station. We built the International Space Station by taking large parts into space and assembling them. Someday welders will be required to build even larger structures in the vacuum of space. **Figure 1-6** is a welding machine designed to be used in space. **Figure 1-7** shows cosmonaut Svetlana Savitskaya, the first woman to space walk and the first person to use a welding and cutting machine in open space. The specialized welder was developed at the E.O. Paton Electric Welding Institute. As the welding techniques are developed for this major project, we will see them being used here on Earth to improve our world.

Welding is used extensively in the manufacture of automobiles, farm equipment, home appliances, computer components, mining equipment, and construction equipment. Railway equipment, furnaces, boilers, air-conditioning units, and hundreds of other products we use in our daily lives are also joined together by some type of welding process.

Items ranging from dental braces to telecommunication satellites are assembled by welding. Very little in our modern world is not produced using some type of welding process.


Larry Jeffus

Welded sculpture, Seattle, Washington.


Larry Jeffus

Roller coaster at Silver Dollar City, Branson, Missouri.


Larry Jeffus

Roller coaster at Silver Dollar City, Branson, Missouri.


Larry Jeffus

Spiral staircase in Missouri City, Texas.

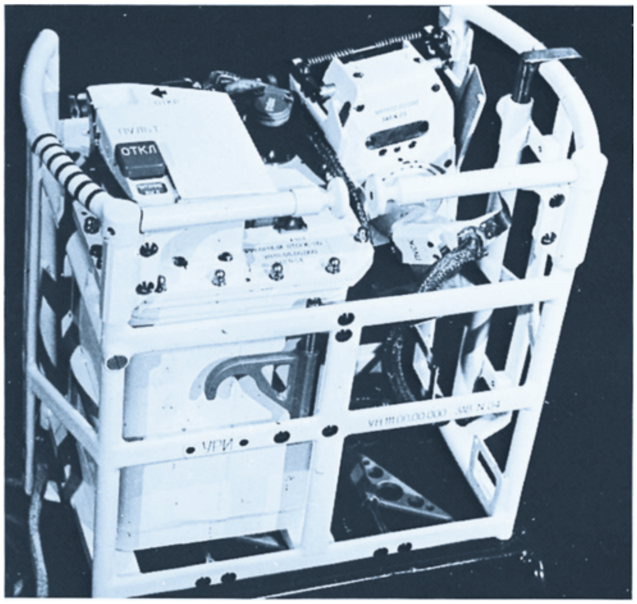

Larry Jeffus

Voyager of the Sea, Haiti.


Larry Jeffus

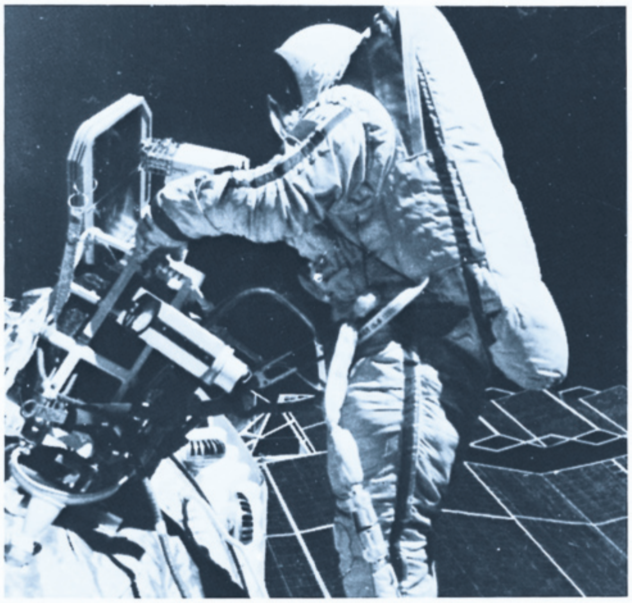
Voyager of the Sea dining room.

FIGURE 1-5 Welded joints are a critical component of structures.



Courtesy of E.O. Paton Electric Welding Institute, Commonwealth of Independent States, the former Soviet Union.

FIGURE 1-6 Machine designed to be used to weld in space.



Courtesy of E.O. Paton Electric Welding Institute, Commonwealth of Independent States, the former Soviet Union.

FIGURE 1-7 A cosmonaut makes a weld outside a space ship.

WELDING AND CUTTING PROCESSES

Welding processes differ greatly in the manner in which heat, pressure, or both heat and pressure are applied and in the type of equipment used. **Table 1-1** lists various welding and allied processes. One hundred twenty-one welding processes are listed, all of which require hammering, pressing, or rolling to affect the coalescence in the weld joint. Other methods bring the metal to a fluid state, and the edges flow together.

The most popular welding processes are as follows: oxyacetylene welding (OAW); shielded metal arc welding (SMAW), often called stick welding; **gas tungsten arc welding (GTAW)**; **gas metal arc welding (GMAW)**; **flux cored arc welding (FCAW)**; and **torch or oxyfuel brazing (TB)**. The two most popular thermal cutting processes are oxy-acetylene cutting (OAC) and plasma arc cutting (PAC).

WELDING PROCESSES

Oxyacetylene Welding, Brazing, and Cutting

Oxyacetylene welding (OAW) and torch brazing (TB) can be done with the same equipment, and **oxyfuel gas cutting (OFC)** uses very similar equipment, **Figure 1-8**.

In OF welding and TB a high-temperature flame is produced at the torch tip by burning oxygen and a fuel gas. The most common fuel gas is acetylene; however, other combinations of oxygen and fuel gases (OF) can be used for welding, such as hydrogen, MAPP, or propane. In OF welding, the base metal is melted and a filler metal may be added to reinforce the weld. No flux is required to make an OF weld of steel.

In TB, the metal is heated to a sufficient temperature but below its melting point so that a brazing alloy can be melted and bond to the hot base metal. A flux may be used to help the brazing alloy bond to the base metal. Both OF welding and TB are used primarily on smaller, thinner-gauge metals.

Shielded Metal Arc Welding (SMAW)

Shielded metal arc welding (SMAW) uses a consumable stick electrode that conducts the welding current from the electrode holder to the work, and as the arc melts the end of the electrode away, it becomes part of the weld metal. Stick electrodes are available in lengths of 12 in., 14-in., and 18 in. (300 mm, 350 mm, and 450 mm). The welding arc vaporizes the solid flux that covers the electrode so that it forms an expanding gaseous cloud to protect the molten weld metal. In addition to fluxes protecting molten weld metal, they also perform a number of beneficial functions for the weld, depending on the type of electrode being used.

SMA welding equipment can be very basic as compared to other welding processes. It can consist of a welding transformer and two welding cables with a work clamp and electrode holder, **Figure 1-9**. There are more types and sizes of SMA welding electrodes than there are filler metal types and sizes for any other welding process. This wide selection of filler metal allows welders to select the best electrode type and size to fit their specific welding job requirements. Therefore, a wide variety of metal types and metal thicknesses can be joined with one machine.

Gas Tungsten Arc Welding (GTAW)

Gas tungsten arc welding (GTAW) uses a nonconsumable electrode made of tungsten. In GTA welding the arc between the electrode and the base metal melts

WELDING AND JOINING PROCESSES

ARC WELDING (AW)

arc stud welding	SW
atomic hydrogen welding	AHW
bare metal arc welding	BMAW
carbon arc welding	CAW
gas carbon arc welding	CAW-G
shielded carbon arc welding	CAW-S
twin carbon arc welding	CAW-T
electrogas welding	EGW
flux cored arc welding	FCAW
gas shielded flux cored arc welding	FCAW-G
self-shielded flux cored arc welding	FCAW-S
gas metal arc welding	GMAW
pulsed gas metal arc welding	GMAW-P
short circuit gas metal arc welding	GMAW-S
gas tungsten arc welding	GTAW
pulsed gas tungsten arc welding	GTAW-P
magnetically impelled arc welding	MIAW
plasma arc welding	PAW
shielded metal arc welding	SMAW
submerged arc welding	SAW
series submerged arc welding	SAW-S

RESISTANCE WEWELDING (RW)

flash welding	FW
pressure-controlled resistance welding	RW-PC
projection welding	PW
resistance seam welding	RSEW
high-frequency seam welding	RSEW-HF
induction seam welding	RSEW-I
mash seam welding	RSEW-MS
resistance spot welding	RSW
upset welding	UW
high-frequency	UW-HF
induction	UW-I

HIGH ENERGY BEAM WELDING (HEBW)

electron beam welding	EBW
high vacuum electron beam welding	EBW-HV
medium vacuum electron beam welding	EBW-MV
nonvacuum electron beam welding	EBW-NV
laser beam welding	LBW

SOLID-STATE WELDING (SSW)

coextrusion welding	CEW
cold welding	CW
diffusion welding	DFW
hot isostatic pressure welding	HIPW
explosion welding	EXW
forge welding	FOW
friction welding	FRW
direct drive friction welding	FRW-DD
friction stir welding	FSW
inertia friction welding	FRW-I
hot pressure welding	HPW
magnetic pulse welding*	MPW
roll welding	ROW
ultrasonic welding	USW

SOLDERING (S)

dip soldering	DS
furnace soldering	FS
induction soldering	IS
infrared soldering	IRS
iron soldering	INS
resistance soldering	RS
torch soldering	TS
ultrasonic soldering	USS
wave soldering	WS

BRAZING (B)

block brazing	BB
carbon arc brazing	CAB
twin carbon arc brazing	TCAB
diffusion brazing	DFB
dip brazing	DB
electron beam brazing	EBB
exothermic brazing	EXB
flow brazing	FLB
furnace brazing	FB
induction brazing	IB
infrared brazing	IRB
laser beam brazing	LBB
resistance brazing	RB
torch brazing	TB

OTHER WELDING AND JOINING

adhesive bonding	AB
braze welding	BW
arc braze welding	ABW
carbon arc braze welding	CABW
electron beam braze welding	EBBW
exothermic braze welding	EXBW
flow welding	FLOW
laser beam braze welding	LBBW
electroslag welding	ESW
consumable guide electroslag welding	ESW-CG
induction welding	IW
percussion welding	PEW
thermite welding	TW

OXYFUEL GAS WELDING (OFW)

air acetylene welding	AAW
oxyacetylene welding	OAW
oxyhydrogen welding	OHW
pressure gas welding	PGW

ALLIED PROCESSES

THERMAL GOUGING (TG)

carbon arc gouging	CAG
oxygen gouging	OG
plasma arc gouging	PAG

THERMAL SPRAYING (THSP)

arc spraying	ASP
flame spraying	FLSP
wire flame spraying	FLSP-W
high velocity oxyfuel spraying	HVOF
plasma spraying	PSP
vacuum plasma spraying	VPSP

THERMAL CUTTING (TC)

OXYGEN CUTTING (OC)

flux cutting	OC-F
metal powder cutting	OC-P
oxyfuel gas cutting	OFC
oxyacetylene cutting	OFC-A
oxyhydrogen cutting	OFC-H
oxynatural gas cutting	OFC-N
oxypropane cutting	OFC-P
oxygen arc cutting	OAC
oxygen lance cutting	OLC

HIGH ENERGY BEAM CUTTING (HEBC)

electron beam cutting	EBC
laser beam cutting	LBC
air	LBC-A
evaporative	LBC-EV
inert gas	LBC-IG
oxygen	LBC-O

ARC CUTTING (AC)

carbon arc cutting	CAC
air carbon arc cutting	CAC-A
gas metal arc cutting	GMAC
gas tungsten arc cutting	GTAC
plasma arc cutting	PAC
shielded metal arc cutting	SMAC

*New welding process

TABLE 1-1 Master Chart of Welding, Joining, and Allied Processes

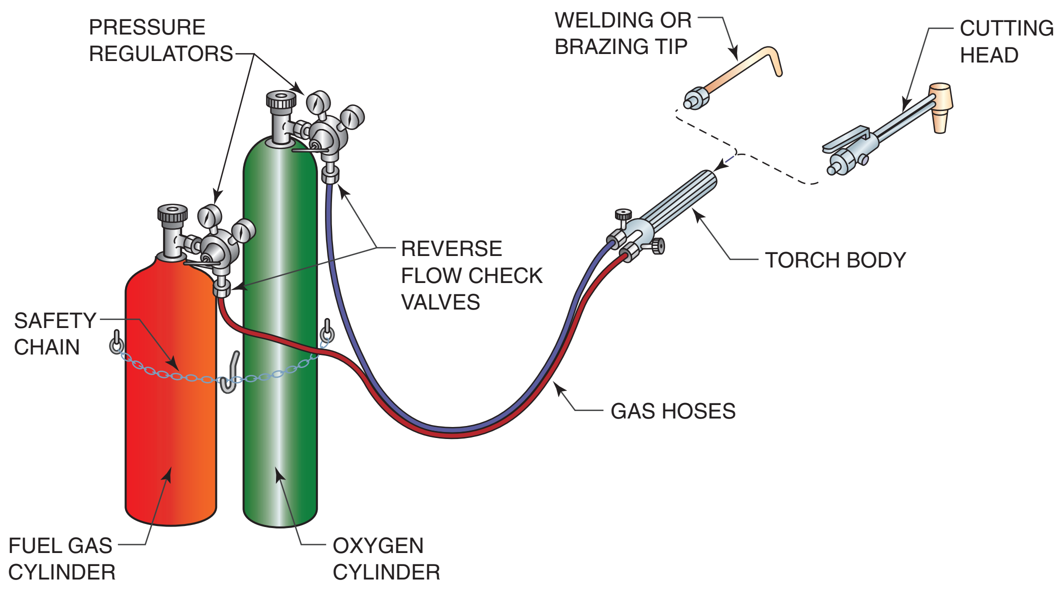


FIGURE 1-8 Oxyfuel welding and cutting equipment.

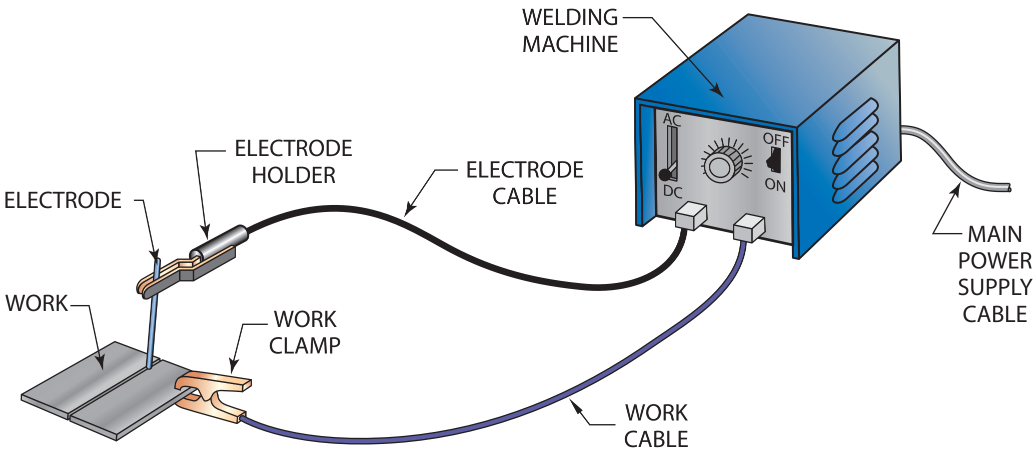


FIGURE 1-9 Shielded metal arc welding equipment.

the base metal and the end of the filler metal as it is manually dipped into the molten weld pool. A shielding gas flowing from the gun nozzle protects the molten weld metal from atmospheric contamination. A foot or thumb remote control switch may be added to the basic GTA welding setup to allow the welder better control, **Figure 1-10**. This remote control switch is often used to start and stop the welding current as well as make adjustments in the power level.

GTA welding is the cleanest of all the manual welding processes. But because there is no flux used to clean the weld in GTA welding, all surface contamination, such as oxides, oil, dirt, and others, must be cleaned from the part being welded and the filler metal so they do not contaminate the weld. Even though GTA welding is slower and requires a higher skill level as compared to other manual welding processes, it is still in demand because it can be used to make extremely high-quality welds in applications where weld integrity is critical. And there are metal alloys that can be joined only with the GTA welding process.

Gas Metal Arc Welding (GMAW)

Gas metal arc welding (GMAW) uses a solid electrode wire that is continuously fed from a spool, through the welding cable assembly, and out through the gun. A shielding gas flows through a separate tube in the cable assembly, out of the welding gun nozzle, and around the electrode wire. The welding power flows through a cable in the cable assembly and is transferred to the electrode wire at the welding gun. The GMA weld is produced as the arc melts the end of the continuously fed filler electrode wire and the surface of the base metal. The molten electrode metal transfers across the arc and becomes part of the weld. The gas shield flows out of

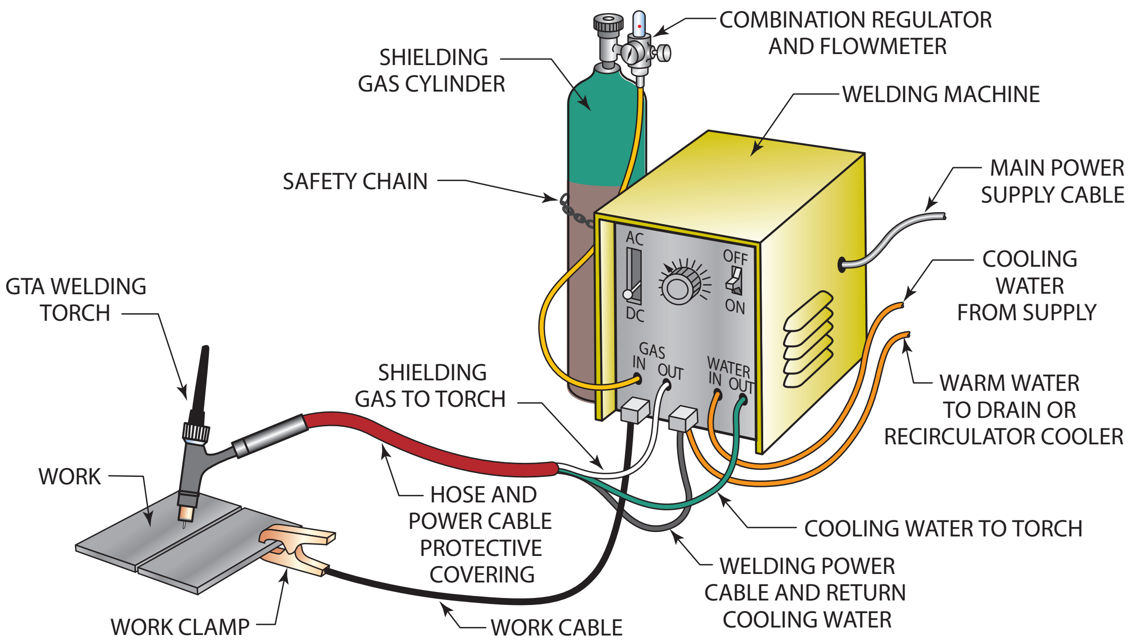


FIGURE 1-10 Gas tungsten arc welding equipment.

the welding gun nozzle to protect the molten weld from atmospheric contamination.

GMA welding is extremely fast and economical because it can produce long welds rapidly that require very little postweld cleanup. This process can be used to weld metal ranging in thickness from thin-gauge sheet metal to heavy plate by making only a few changes in the welding setup.

Flux Cored Arc Welding (FCAW)

Flux cored arc welding (FCAW) uses a flux core electrode wire that is continuously fed from a spool, through the welding cable assembly, and out through the gun. The welding power also flows through the cable assembly. Some welding electrode wire types must be used with a shielding gas, as in GMA welding, but others have enough shielding produced as the flux core vaporizes. The welding current melts both the filler wire and the base metal. When some of the flux vaporizes, it forms a gaseous cloud that protects the surface of the weld. Some of the flux that melts travels across the arc with the molten filler metal where it enters the molten weld pool. Inside the molten weld metal, the flux gathers the impurities and floats them to the surface, where it forms a slag covering on the weld as it cools.

Although slag must be cleaned from the FCA welds after completion, the advantages of the process are its high quality, versatility, and welding speed, which offset this requirement.

Gas metal arc welding and flux cored arc welding are very different welding processes, but they use very similar welding equipment, **Figure 1-11**. Both GMA and FCA welding are classified as semiautomatic processes because the filler metal is automatically fed into the welding arc, and the welder manually moves the welding gun along the joint being welded. GMA and FCA welding are the first choice for many welding fabricators because these processes are cost-effective, produce high-quality welds, and are flexible and versatile. In addition to welding supply stores, many others stores such as hardware stores, building supply stores, automotive supply stores, and others carry GMA/FCA welding equipment and filler metals.

THERMAL CUTTING PROCESSES

There are a number of thermal cutting processes such as oxyfuel cutting (OFC) and plasma arc cutting (PAC). They are the most commonly used in most welding shops. Air carbon arc (AAC) cutting is also frequently used, and many larger fabrication shops have started using laser beam cutting (LBC).

Oxyfuel Gas Cutting

Oxyfuel gas cutting uses the high-temperature flame to heat the surface of a piece of steel to a point where a forceful stream of oxygen flowing out a center hole in the tip causes the hot steel to burn away, leaving a gap or cut. Because OF cutting relies on the rapid oxidation of the base metal at elevated temperatures to make a cut, the types of metals and alloys it can be used on are limited. OF cutting can be used on steel from a fraction of an inch thick to several feet depending on the capacity of the torch and tip being used.

Plasma Arc Cutting

Plasma arc cutting (PAC) uses a stiff, highly ionized, extremely hot column of gas to almost instantly vaporize the metal being cut. Most ionized plasma is formed as high-pressure air is forced through a very small opening between

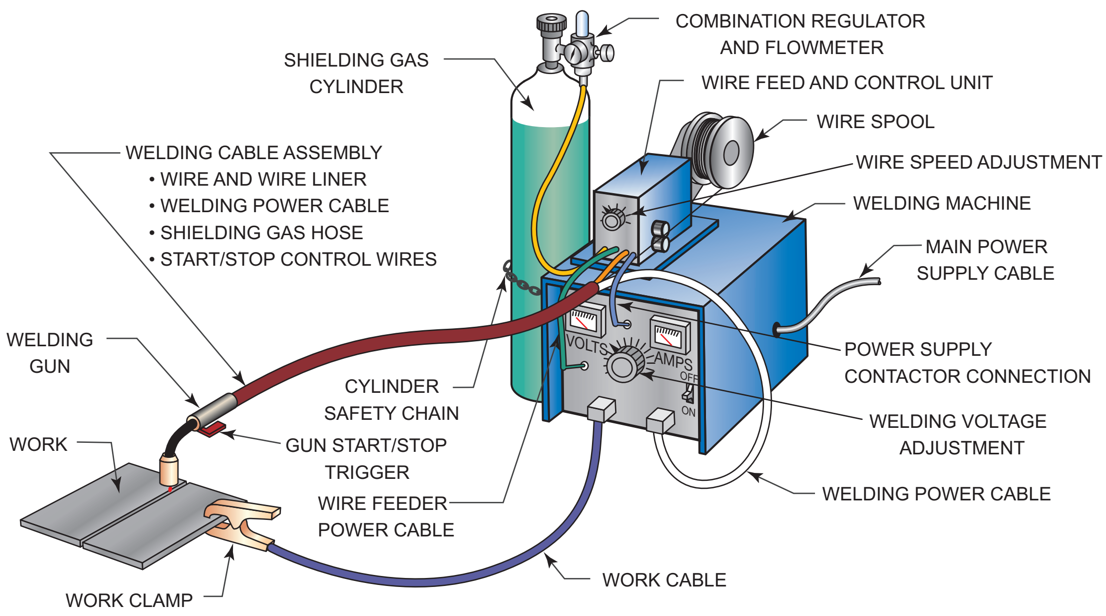


FIGURE 1-11 Gas metal arc welding equipment.

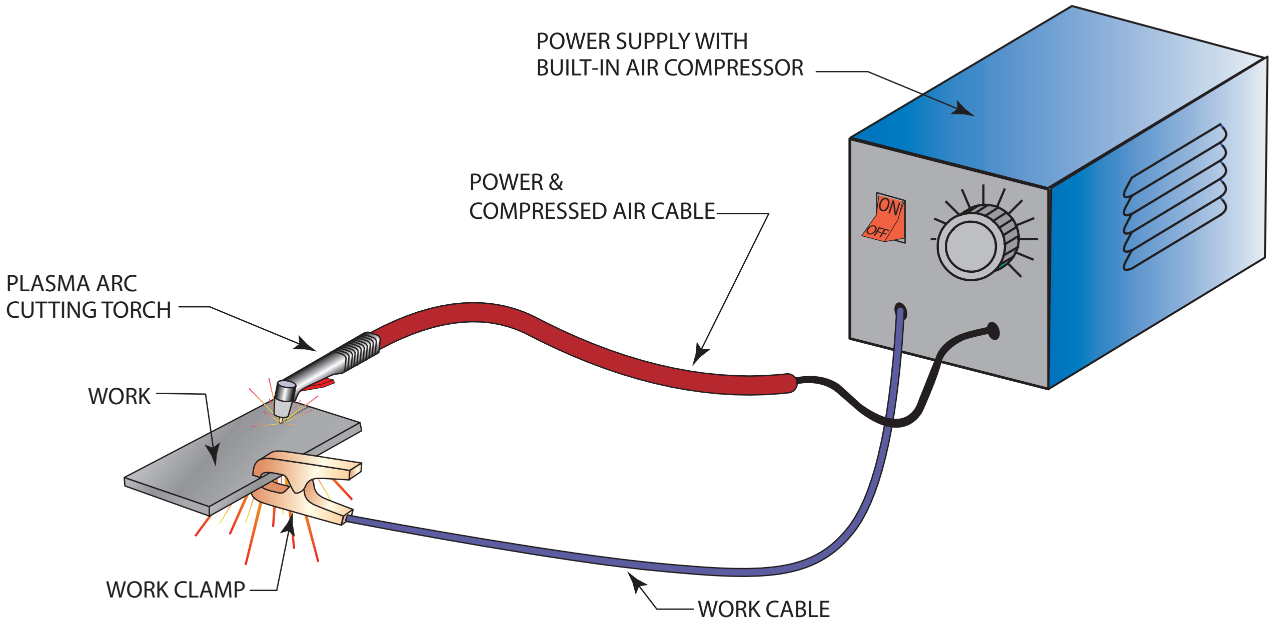


FIGURE 1-12 Plasma arc cutting equipment.

a tungsten electrode and the torch tip, **Figure 1-12**. As the air is ionized, it heats up, expands, and exits the torch tip at supersonic speeds. PAC does not rely on rapid oxidation of the metal being cut, like OFC, so almost any metal or alloy can be cut.

PA cutting equipment consists of a transformer power supply, plasma torch and cable, work clamp and cable, and an air supply. Some PA cutting equipment has self-contained air compressors. Because the PA cutting process can be performed at some very high travel speeds, it is often used on automated cutting machines. The high travel speeds and very low heat input help to reduce or eliminate part distortion, a common problem with some OF cutting.

SELECTION OF THE JOINING PROCESS

The selection of the joining process for a particular job depends on many factors. No one specific rule controls the welding process to be selected for a certain job. The following are a few of the factors that must be considered when choosing a joining process.

- Availability of equipment—The types, capacity, and condition of equipment that can be used to make the welds.
- Repetitiveness of the operation—How many of the welds will be required to complete the job, and are they all the same?
- Quality requirements—Is this weld going to be used on a piece of furniture, to repair a piece of equipment, or to join a pipeline?
- Location of work—Will the weld be in a shop or on a remote job site?
- Materials to be joined—Are the parts made out of a standard metal or some exotic alloy?
- Appearance of the finished product—Will this be a weldment that is needed only to test an idea, or will it be a permanent structure?
- Size of the parts to be joined—Are the parts small, large, or different sizes, and can they be moved or must they be welded in place?
- Time available for work—Is this a rush job needing a fast repair, or is there time to allow for preweld and postweld cleanup?
- Skill or experience of workers—Do the welders have the ability to do the job?
- Cost of materials—Will the weldment be worth the expense of special equipment materials or finishing time?
- Code or specification requirements—Often the selection of the process is dictated by the governing agency, codes, or standards.

The welding engineer and/or the welder not only must decide on the welding process but also must select the method of applying it. The following methods, **manual operation**, **semiautomatic operation**, **machine operation**, **automatic operation**, and **automated operation**, are used to perform welding, cutting, or brazing operations.

- **Manual**—The welder is required to manipulate the entire process.
- **Semiautomatic**—Filler metal is added automatically, and all other manipulation is done manually by the welder.
- **Machine**—Operations are done mechanically under the observation and correction of a welding operator.

- **Automatic—**Operations are performed repeatedly by a machine that has been programmed to do an entire operation without interaction of the operator.
- **Automated—**Operations are performed repeatedly by a robot or other machine that is programmed flexibly to do a variety of processes.

OCCUPATIONAL OPPORTUNITIES IN WELDING

The American welding industry has contributed to the widespread growth of the welding and allied processes. Without welding, much of what we use on a daily basis could not be manufactured. The list of these products grows every day, thus increasing the number of jobs for people with welding skills. The need to fill these well-paying jobs is not concentrated in major metropolitan areas, but rather is found throughout the country and the world. Because of the diverse nature of the welding industry, the exact job duties of each skill area will vary. The following are general descriptions of the job classifications used in our profession; specific tasks may vary from one location to another.

Welders perform the actual welding. They are the skilled craftspeople who, through their own labor, produce the welds on a variety of complex products, **Figure 1-13**. In many industries, the welder, welding operator, and tack welder must be able to pass a performance test to a specific code or standard.

Larry Jeffus

(A)

Larry Jeffus

(B)

Larry Jeffus

(C)

FIGURE 1-13 Amusement parks like Silver Dollar City in Branson, Missouri require a lot of talented welders to produce attractions such as these. (A) Fabricating an antique train engine to be used in a parade. (B) Air-powered guns for launching toy balls. (C) The Branson Belle paddleboat.

Tack welders, also skilled workers, often help the welder by making small welds to hold parts in place. The tack weld must be correctly applied so that it is strong enough to hold the assembly and still not interfere with the finished welding.

Welding operators, often skilled welders, operate machines or automatic equipment used to make welds.

Welders' helpers are employed in some welding shops to clean slag and grind welds and help the welder.

Welder assemblers, or welder fitters, position all the parts in their proper places and make them ready for the tack welders. These skilled workers must be able to interpret blueprints and welding procedures. They must also have knowledge of the effects of contraction and expansion of the various types of metals.

Welding inspectors are often required to hold a special **certification** such as the one supervised by the American Welding Society known as Certified Welding Inspector (CWI). To become a CWI, candidates must pass a test covering the welding process, blueprint reading, weld symbols, metallurgy, codes and standards, and inspection techniques. Vision screening is also required on a regular basis, once the technical skills have been demonstrated.

Welding shop supervisors may or may not weld on a regular basis, depending on the size of the shop. In addition to their welding skills, they must demonstrate good management skills by effectively planning jobs and assigning workers.

Welding salespersons may be employed by supply houses or equipment manufacturers. These jobs require a broad understanding of the welding process as well as good marketing skills. Good salespersons are able to

provide technical information about their products to convince customers to make a purchase.

Welding shop owners are often welders who have a high degree of skill and knowledge of small business management and prefer to operate their own businesses. These individuals may specialize in one field, such as hardfacing, repair and maintenance, or specialty fabrications, or they may operate as subcontractors of manufactured items. A welding business can be as small as one individual, one truck, and one portable welder, or as large as a multimillion-dollar operation employing hundreds of workers.

Welding engineers design, specify, and oversee the construction of complex weldments. The welding engineer may work with other engineers in areas such as mechanics, electronics, chemicals, or civil engineering in the process of bringing a new building, ship, aircraft, or product into existence. The welding engineer is required to know all of the welding process and metallurgy, as well as to have good math, reading, communication, and design skills. This person usually has an advanced college degree and possesses a professional certification.

Related Welding Jobs The highest-paid welders are those who have the education and skills to read blueprints and do the required work to produce a weldment to strict specifications.

Large industrial firms employ workers who serve as support for the welders. These engineers and technicians must have knowledge of chemistry, physics, metallurgy, electricity, and mathematics. Engineers are responsible for research, design, development, and fabrication of a project. Technicians work as part of the engineering staff. These individuals may oversee the actual work for the engineer by providing the engineer with progress reports as well as chemical, physical, and mechanical test results. Technicians may also require engineers to build prototypes for testing and evaluation.

Another group of workers employed by industry does layouts or makes templates. These individuals have had drafting experience and have knowledge of operations such as punching, cutting, shearing, twisting, and forming, among others. The layout is generally done directly on the material. A template is used for repetitive layouts and is made from sheet metal or other suitable materials.

Some operators use handheld torches, and others are skilled operators of oxyfuel cutting machines. These machines range from simple mechanical devices to highly sophisticated, computer-controlled, multiple-head machines that are operated by specialists, **Figure 1-14**.

TRAINING FOR WELDING OCCUPATIONS

Generally, several months of training are required to learn to weld. To become a skilled welder, both welding school and on-the-job experience are required. Because of the diverse nature of the welding industry, no single list of skills can be used to meet every job's requirements. However, there are specific skills that are required of most entry-level welders. This text covers those skill requirements.

Courtesy of ESAB Welding & Cutting Products

FIGURE 1-14 Numerical control oxygen cutting machine.

Some welding shops require that welders have proficiency in reading, writing, math, communication, and science, as well as good work habits and an acceptance of close supervision. Some welding jobs may also require a theoretical knowledge of welding, blueprint reading, welding symbols, metal properties, and electricity. A few of the jobs that require less skill can be learned after a few months of on-the-job training. The fabrication of certain alloys requires knowledge of metallurgical properties as well as the development of a greater skill in cutting and welding them.

JOB-RELATED SKILLS

In addition to welding skills, an entry-level welder must possess workplace skills such as teamwork, leadership, integrity, honesty, organizational skills, time management, understand the importance of workplace diversity, and the Equal Employment Opportunity law.

Robotics and computer-aided manufacturing (CAM) both require more than a basic understanding of the welding process; they require that the student be computer literate.

A young person planning a career as a welder needs good eyesight, manual dexterity, hand-and-eye coordination, and understanding of welding technology. For entry into manual welding jobs, employers prefer to hire young people who have high school or vocational training in welding processes. Courses in drafting, blueprint reading, mathematics, and physics are also valuable.

Beginning a Welding Career

Beginners in welding who have no training often start in manual welding production jobs that require minimum skill. Occasionally, they first work as helpers and are later moved into welding jobs. General helpers, if they show promise, may be given a chance to become welders by serving as helpers to experienced welders.

A formal apprenticeship is usually not required for general welders. A number of large companies have welding apprenticeship programs. The military has programs in welding at several of its installations.

Skill and technical knowledge requirements are higher in some industries. In the fields of atomic energy, aerospace, and pressure vessel construction, high standards for welders must be met to ensure that weldments will withstand the critical forces that they will be subjected to in use.

Job Prospects

After two years of training at a vocational school or technical institute, the skilled welder may qualify as a technician. Technicians are generally involved in the interpretation of engineers' plans and instructions. Employment of welders is increasing rapidly for a number of reasons.

Many more skilled welders will be needed for maintenance and repair work in the expanding metalworking industries. The number of welders in production work is expected to increase in plants manufacturing sheet metal products, pressure vessels, boilers, railroads, storage tanks, air-conditioning equipment, ship yards, pipe lines, petrochemical plants, and all other areas of energy exploration and production. The construction industry will need an ever-increasing number of good welders as the use of welded steel buildings grows.

Before being assigned a job where service requirements of the weld are critical, welders usually must pass a certification test given by an employer. In addition, some localities require welders to obtain a license for certain types of outside construction.

THINK GREEN

All welding and cutting processes consume large quantities of energy and materials, and some produce environmental pollution. It is important that you always look at ways to minimize the impact these processes have on our environment. For example, if a spill occurs, notify your supervisor and clean it up promptly and properly. Always look for ways to be better stewards of our environment.

After welders, welding operators, or tack welders have received a certification or **qualification** by passing a standardized test, they are only allowed to make welds covered by that specific test. The welding certification is very restrictive; it allows a welder to perform only code welds covered by that test. Certifications are usually good for a maximum of six months unless a welder is doing code-quality welds routinely. As a student, you should check into the acceptance of a welding qualification test before investing time and possibly money in the test.

AWS SENSE WELDER CERTIFICATION

The **American Welding Society (AWS)** has developed two levels of certification for welders. The first level, Entry-Level Welder, is for the beginning welder, and Level II is for the more skilled welders. The AWS Schools Exceling through National Skills Standards Education (SENSE) certifications have gained widespread acceptance by the industry. SENSE certifications allow welders to demonstrate their skills on a standard welding test.

The AWS SENSE guidelines have been established as the minimum skill standards according to AWS QC10 Specifications for Qualification and Certification for Entry-Level I Welders and according to AWS QC11 Specifications for Qualification and Certification for Level II—Advanced Welders.

Schools that become Participating Organizations of the AWS SENSE program can forward the records of students who have passed the required knowledge test and one or more workmanship standard to the AWS. The AWS will then post the students' information on the National

Registry of SENSE Program Welders. The National Registry is a web-based program available to employers looking for skilled welders.

LEVEL I QUALIFICATION PROCEDURES

The Entry Level Welder SENSE program is divided into nine modules. The first three modules relate to practical knowledge that is common to all areas of welding and that welders must have to succeed in the welding field. Modules 4 through 7 relate to welding performance (skills) in each of the major welding processes.

Documentation must be kept for all the knowledge tests and workmanship tests. Examples of forms that can be used for student record-keeping can be found in Appendix I, II, and III.

Practical Knowledge Qualification—Written Test

The three areas covered in the knowledge modules are: Module 1, Occupational Orientation; Module 2, Safety and Health of Welders; and Module 3, Drawing and Welding Symbol Interpretation. The chapters in this textbook that relate to these performance qualifications areas are listed in **Table 1-2**.

As part of the qualification process students must pass a closed book test regarding Module 2 (Safety and Health of Welders) with minimum grade of 90%. Closed book test regarding material covered in Modules 1 and 3 must be passed with a minimum grade of 70%.

Performance Qualification—Workmanship Samples and Test Plates

Each of the four major welding processes are covered in Modules 4 through 7: Module 4, Shielded Metal Arc Welding (SMAW) Principles and Practices; Module 5, Gas Metal Arc Welding (GMAW, GMAW-S) Principles and Practices; Module 6, Flux Cored Arc Welding (FCAW, FCAW-G/GM) Principles and Practices; and Module 7, Gas Tungsten Arc Welding (GTAW) Principles and Practices. The chapters in this textbook that relate to these performance qualifications areas are listed in **Table 1-3**.

Level 1 Module	Welding Process	Chapter Number(s)
4	SMAW	3, 4, 5, and 6
5	GMAW & GMAW-S	10, 11, 14, and 15
6	FCAW-S & FCAW-G	12, 13, 14, and 15
7	GTAW	16, 17, 18, and 19
8 Unit 1	OFC Manual	7
8 Unit 2	OFC Machine	7
8 Unit 3	PAC	8
8 Unit 4	CAC-A	9
9	Inspection and Testing	6, 15, 19, and 24

TABLE 1-3 AWS SENSE Performance Skills for Level I Entry-Level Welder Qualification

Each of the welding performance qualification workmanship tests has a list of acceptable limits for discontinuities that must be met for the student to pass. Students can pass one or more of the workmanship qualification standard welding tests.

The welding practices in this textbook that are based on these SENSE standards are identified as "AWS SENSE Level I." The practices are set up in the same way as a Welding Procedure Specification (WPS) for SMA welding of plate and pipe. The welding and testing procedures are in accordance with the AWS QC10 standards.

Thermal Cutting Principles and Practices

Module 8, Thermal Cutting Principles and Practices, is divided into four units, with each covering different types of thermal cutting: Unit 1, Manual Oxyfuel Gas Cutting (OFC); Unit 2, Mechanized Oxyfuel Gas Cutting (OFC); Unit 3, Plasma Arc Cutting (PAC); and Unit 4, Air Carbon

Module Number	Knowledge Subjects	Chapter Number(s)	Notes
1	Occupational Orientation	1	A variety of welding occupations are included in the vignettes at the beginning of each Section and in the short stories at the ends of Chapters.
2	Safety and Health of Welders	2	Each welding skill chapter has process-related safety precautions.
3	Drawing and Welding Symbol Interpretation	23 and 24	Most of the practices in each of the welding skill chapters have drawings for the student to follow.

TABLE 1-2 AWS SENSE Knowledge Subjects for Level I Entry-Level Welder Qualification

Arc Cutting (CAC-A). The chapters in this textbook that relate to these performance qualifications areas are listed in Table 1-3.

Welding Inspection and Testing Principles and Practices

Module 9 covers two main areas of inspection and testing. The first covers the examination of cut surfaces and edges of prepared base metal parts. The second covers the examination of tack welds, intermediate welding layers, and completed welds, Table 1-3.

LEVEL II ADVANCED WELDER QUALIFICATION

Level II Advanced Welding Qualifications are divided into two sections: Knowledge Subjects, which require students to be tested, and Performance Testing, which requires students to pass a welding skill test, **Table 1-4**. For Level II, the students must pass the safety test with a grade of at least 90% and the other knowledge areas with a grade of at least 75%.

The welding practices in this textbook that are based on these SENSE standards are identified as "AWS SENSE Level II." The practices are set up in the same way as a Welding Procedure Specification (WPS) for SMA welding of plate and pipe. The welding and testing procedures are in accordance with the AWS QC11 standards.

SKILLSUSA

Each year SkillsUSA sponsors a series of welding skill competitions for its student members. Students can begin by joining their local SkillsUSA chapter. They can then compete in local, regional, and state competitions. Each time, the students with the best welding skills and knowledge can advance to the next level of competition. Contestants are challenged with a written test and must show their proficiency in welding and fabrication. There is a national SkillsUSA Olympics competition held each year in Kansas City, Missouri. The winners at the national competition can then go on to the International Skill Olympics. The international competition is held in a different country each year. Like most professional organizations, SkillsUSA emphasizes community service and citizenship as key components to the philosophy of the organization.

EXPERIMENTS AND PRACTICES

A number of the chapters in this book contain both experiments and practices. These are intended to help you develop your welding knowledge and skills.

The experiments are designed to allow you to see what effect changes in the process settings, operation, or techniques have on the type of weld produced. The knowledge gained from the experiments will help you troubleshoot welding problems. When you try an experiment, you should observe and possibly take notes on how

Knowledge Subjects	Chapter Number(s)	Notes
Mathematics	20	
Employment Skills	1	Employment Skills are included in the vignettes at the beginning of each Section and in the short stories at the ends of Chapters.
Safe Practices	2	Each welding skill chapter has process-related safety precautions.
Welding Terms and Definitions	Glossary	Key terms are listed at the beginning of each chapter and identified and defined in the chapter text.
Layout/Fitup Principles and Practices	23 and 25	Welder Qualification and Certification Workmanhip standards in Chapters 6, 15, 19, 21, 22, and 23 all require layout and fitup skills.
Codes/Standards	24	
Qualification and Certification	6, 15, 19	
Welding Specifications	6, 15, 19, and 23	
Welding Theory	3, 10, 12, 16, and 25	
Weldability	26	
Welding Inspection and Testing	6, 15, 19, and 24	
Cutting Theory	7, 8, and 9	
Cutting Terms and Definitions	7, 8, and 9	

TABLE 1-4 AWS SENSE Knowledge Subjects for Level 2 Advanced Welders

the change affected the weld. Often as you make a weld, it will be necessary for you to make changes in your equipment settings or your technique to ensure you are making an acceptable weld. By watching what happens when you make the changes in the welding shop, you will be better prepared to decide on changes required to make good welds on the job.

It is recommended that you work in a small group as you try the experiments. When trying the experiments in a small group, one person can be welding, one can be adjusting the equipment, and the others can be recording the machine settings and weld effects. This also allows you to watch the weld change more closely if someone is welding as you look on. Then, as a group member, changing places will reinforce your learning.

The practices are designed to build your welding skills. Each practice tells you in detail what equipment, supplies, and tools you will need as you develop the specific skill. In most chapters, the practices are easy in the beginning and become progressively harder. Welding is a skill that requires you to develop in stages from the basic to the more complex.

Each practice gives the evaluation or acceptable limits for the weld. All welds have some discontinuities, but if they are within the acceptable limits, then they are not defects. Instead, they are called flaws. As you practice your welding, keep in mind the acceptable limits so that you can progress to the next level when you have mastered the process and weld you are working on.

WELDING VIDEO SERIES

Cengage Learning, in cooperation with the author, has produced a series of videotapes. Each of the four tape sets covers specific equipment setup and operation for welding, cutting, soldering, or brazing. When there are specific skills shown both in this textbook and on a videotape, you will see a framed shot from the video, as shown in **Figure 1-15**. Reading the material, watching the video, and practicing should help you to develop your welding skills more rapidly.

Larry Jeffus

FIGURE 1-15 This GMA welding can be seen in the Gas Metal Arc Welding video series on tape 2.

METRIC UNITS

Both standard and metric (SI) units are given in this text. The SI units are in parentheses ( ) following the standard unit. When nonspecific values are used—for example, "set the gauge at 2 psig" where 2 is an approximate value—the SI units have been rounded to the nearest whole number. Rounding occurs in these cases to agree with the standard value and because whole numbers are easier to work with. The only time that SI units are not rounded is when the standard unit is an exact measurement.

Often students have difficulty understanding metric units because exact conversions are used even when the standard measurement was an approximation. Rounding the metric units makes understanding the metric system much easier, **Table 1-5**. Estimating the approximate conversion from one unit type to another makes it possible to quickly have an idea of how large or heavy an object is. When estimating a conversion, it is not necessary to be concise.

By using this approximation method, you can make most standard-to-metric conversions in your head without needing to use a calculator.

Once you have learned to use approximations for metric, you will find it easier to make exact conversions whenever necessary. Conversions must be exact in the shop when a part is dimensioned with one system's units and the other system must be used to fabricate the part. For that reason you must be able to make those conversions. **Table 1-6** and **Table 1-7** are set up to be used with or without the aid of a calculator. Many calculators today have built-in standard–metric conversions. Of course, it is a good idea to know how to make these conversions with and without these aids. Practice making such conversions whenever the opportunity arises.

1/4 inch	=	6 mm
1/2 inch	=	13 mm
3/4 inch	=	18 mm
1 inch	=	25 mm
2 inches	=	50 mm
1/2 gal	=	2 L
1 gal	=	4 L
1 lb	=	1/2 K
2 lb	=	1 K
1 psig	=	7 kPa
1°F	=	2°C

TABLE 1-5 Conversion Approximations

TEMPERATURE

Units

°F (each 1° change)	=	0.555°C (change)
°C (each 1° change)	=	1.8°F (change)
32°F (ice freezing)	=	0°Celsius
212°F (boiling water)	=	100°Celsius
–460°F (absolute zero)	=	0°Rankine
–273°C (absolute zero)	=	0°Kelvin

Conversions

°F to °C ______ °F – 32 = ______ × .555 = ______ °C

°C to °F ______ °C × 1.8= ______ + 32 = ______ °F

LINEAR MEASUREMENT

Units

1 inch	=	25.4 millimeters
1 inch	=	2.54 centimeters
1 millimeter	=	0.0394 inch
1 centimeter	=	0.3937 inch
12 inches	=	1 foot
3 feet	=	1 yard
5280 feet	=	1 mile
10 millimeters	=	1 centimeter
10 centimeters	=	1 decimeter
10 decimeters	=	1 meter
1000 meters	=	1 kilometer

Conversions

in. to mm	______ in.	×	25.4	=	______ mm	
in. to cm	______ in.	×	2.54	=	______ cm	
ft to mm	______ ft	×	304.8	=	______ mm	
ft to m	______ ft	×	0.3048	=	______ m	
mm to in.	______ mm	×	0.0394	=	______ in.	
cm to in.	______ cm	×	0.3937	=	______ in.	
mm to ft	______ mm	×	0.00328	=	______ ft	
m to ft	______ m	×	3.28	=	______ ft	

AREA MEASUREMENT

Units

1 sq in.	=	0.0069 sq ft
1 sq ft	=	144 sq in.
1 sq ft	=	0.111 sq yd
1 sq yd	=	9 sq ft
1 sq in.	=	645.16 sq mm
1 sq mm	=	0.00155 sq in.
1 sq cm	=	100 sq mm
1 sq m	=	1000 sq cm

Conversions

sq in. to sq mm ______ sq in. × 645.16 = ______ sq mm

sq mm to sq in. ______ sq mm × 0.00155 = ______ sq in.

VOLUME MEASUREMENT

Units

1 cu in.	=	0.000578 cu ft
1 cu ft	=	1728 cu in.
1 cu ft	=	0.03704 cu yd
1 cu ft	=	28.32 L
1 cu ft	=	7.48 gal (U.S.)
1 gal (U.S.)	=	3.737 L
1 cu yd	=	27 cu ft
1 gal	=	0.1336 cu ft
1 cu in.	=	16.39 cu cm
1 L	=	1000 cu cm
1 L	=	61.02 cu in.
1 L	=	0.03531 cu ft
1 L	=	0.2642 gal (U.S.)
1 cu yd	=	0.769 cu m
1 cu m	=	1.3 cu yd

Conversions

cu in. to L	______ cu in.	×	0.01638	=	______ L
L to cu in.	______ L	×	61.02	=	______ cu in.
cu ft to L	______ cu ft	×	28.32	=	______ L
L to cu ft	______ L	×	0.03531	=	______ cu ft
L to gal	______ L	×	0.2642	=	______ gal
gal to L	______ gal	×	3.737	=	______ L

WEIGHT (MASS) MEASUREMENT

Units

1 oz	=	0.0625 lb
1 lb	=	16 oz
1 oz	=	28.35 g
1 g	=	0.03527 oz
1 lb	=	0.0005 ton
1 ton	=	2000 lb
1 oz	=	0.283 kg
1 lb	=	0.4535 kg
1 kg	=	35.27 oz
1 kg	=	2.205 lb
1 kg	=	1,000 g

Conversions

lb to kg	______ lb	×	0.4535	=	______ kg
kg to lb	______ kg	×	2.205	=	______ lb
oz to g	______ oz	×	0.03527	=	______ g
g to oz	______ g	×	28.35	=	______ oz

PRESSURE AND FORCE MEASUREMENTS

Units

1 psig	=	6.8948 kPa
1 kPa	=	0.145 psig
1 psig	=	0.000703 kg/sq mm
1 kg/sq mm	=	6894 psig
1 lb (force)	=	4.448 N
1 N (force)	=	0.2248 lb

Conversions

psig to kPa	______ psig	×	6.8948	=	______ kPa
kPa to psig	______ kPa	×	0.145	=	______ psig
lb to N	______ lb	×	4.448	=	______ N
N to lb	______ N	×	0.2248	=	______ psig

VELOCITY MEASUREMENTS

Units

1 in./sec	=	0.0833 ft/sec
1 ft/sec	=	12 in./sec
1 ft/min	=	720 in./sec
1 in./sec	=	0.4233 mm/sec
1 mm/sec	=	2.362 in./sec
1 cfm	=	0.4719 L/min
1 L/min	=	2.119 cfm

Conversions

ft/min to in./sec ____ ft/min × 720 = ____ in./sec

in./min to mm/sec ____ in./min × .4233 = ____ mm/sec

mm/sec. to in./min ____ mm/sec × 2.362 = ____ in./min

cfm to L/min ____ cfm × 0.4719 = ____ L/min

L/min to cfm ____ L/min × 2.119 = ____ cfm

TABLE 1-6 Table of Conversions: U.S. Customary (Standard) Units and Metric Units (SI)

U.S. Customer (Standard) Units

°F	=	degrees Fahrenheit				
°R	=	degrees Rankine				
	=	degrees absolute F				
lb	=	pound				
psi	=	pounds per square inch				
	=	lb per sq in.				
psia	=	pounds per square inch absolute				
	=	psi + atmospheric pressure				
in.	=	inches	=	in.	=	″
ft	=	foot or feet	=	ft	=	′
sq in.	=	square inch	=	in.		
sq ft	=	square foot	=	ft		
cu in.	=	cubic inch	=	in.		
cu ft	=	cubic foot	=	ft		
ft-lb	=	foot-pound				
ton	=	ton of refrigeration effect				
qt	=	quart				

Metric Units (SI)

°C	=	degrees Celsius
°K	=	Kelvin
mm	=	millimeter
cm	=	centimeter
cm^2	=	centimeter squared
cm^3	=	centimeter cubed
dm	=	decimeter
dm^2	=	decimeter squared
dm^3	=	decimeter cubed
m	=	meter
m^2	=	meter squared
m^3	=	meter cubed
L	=	liter
g	=	gram
kg	=	kilogram
J	=	joule
kJ	=	kilojoule
N	=	newton
Pa	=	pascal
kPa	=	kilopascal
W	=	watt
kW	=	kilowatt
MW	=	megawatt

Miscellaneous Abbreviations

P	=	pressure	sec	=	seconds
h	=	hours	r	=	radius of circle
D	=	diameter	π	=	3.1416 (a constant used in determining the area of a circle)
A	=	area			
V	=	volume			
∞	=	infinity			

TABLE 1-7 Abbreviations and Symbols

Summary

Welding is a very diverse trade. Almost every manufactured product utilizes a welding or joining process in its production. Products that are produced by welding range from small objects, such as sunglasses and dental braces, to larger structures, such as buildings, ships, and space shuttles. Your knowledge and understanding of the various processes and their applications will provide you with employable skills that can result in a rich and rewarding career in the welding field. The art and science of joining metals has been around for centuries, and with changes and improvements in materials, equipment, and supplies, it will be with us through the remainder of the twenty-first century.

Review

1. What type of welding uses a hammer to join heated and softened metal?
2. What advantage does resistance welding have over forge welding?
3. What term describes the fusion or growing together of the grain structure of the materials being welded?
4. Welding is defined as a joining process that produces coalescence of materials by heating them with or without the application of what?
5. Name three items that are manufactured using welding.
6. Name three popular welding processes.
7. What does shielded metal arc welding (SMAW) use to conduct the welding current from the electrode holder to the work?
8. What is the purpose of the solid flux that covers the electrode?
9. What protects the molten weld metal from atmospheric contamination in GTAW welding?

10. Why is it important to clean all contamination such as oxides, oil, and dirt off of the surface of the part being welded with GTA welding?
11. What welding process uses a solid electrode wire that is continuously fed from a spool, through the welding cable assembly, and out through the gun?
12. What are the advantages of GMA welding?
13. How is a flux cored arc welding (FCAW) electrode wire different from a gas metal arc welding (GMAW) electrode wire?
14. What two welding processes are semiautomatic processes?
15. How is a high-temperature flame produced at the torch tip in oxyacetylene welding (OAW) and torch brazing (TB)?
16. Name two commonly used thermal cutting processes.
17. Which cutting process uses a forceful stream of oxygen flowing out a center hole in the tip to burn away hot steel?
18. What cutting process uses a stiff, highly ionized, extremely hot column of gas to almost instantly vaporize the metal being cut?
19. List three factors that can help determine which welding process to select for a certain job.
20. Name three methods used to perform welding, cutting, or brazing operations.
21. Name five different types of welding career opportunities.
22. What are some skills that entry-level welders need?
23. What are the names of the two American Welding Society (AWS) levels of certification for welders?
24. What does the AWS abbreviation "SENSE" stand for?
25. What practical knowledge subject areas are covered in Module 1 of the SENSE program?
26. What four welding processes are covered in the SENSE program?
27. What is the name of the organization that sponsors a series of welding skill competitions for welding students?

Chapter 2
Safety in Welding

OBJECTIVES

After completing this chapter, the student should be able to

- discuss types of injuries that can occur and how to prevent them.
- describe personal protective equipment (PPE) used by welders.
- discuss the proper use and maintenance of tools and equipment.
- explain the purpose of safety data sheets (SDSs).
- discuss the benefits of recycling waste material.

KEY TERMS

acetone
acetylene
earmuffs
earplugs
electric shock
electrical ground
electrical resistance
exhaust pickups
flash burn
flash glasses
forced ventilation
full face shield
ground-fault circuit interpreter (GFCI)
goggles
infrared light
natural ventilation
safety data sheet (SDS)
safety glasses
type A fire extinguisher
type B fire extinguisher
type C fire extinguisher
type D fire extinguisher
ultraviolet light
valve protection cap
ventilation
visible light
warning label
welding helmet

INTRODUCTION

Accident prevention is the main intent of this chapter. The safety information included in this text is intended as a guide. There is no substitute for caution and common sense. A safe job is no accident; it takes work to make the job safe. Each person must take personal responsibility for their own safety and the safety of others on the job.

Welding is a very large and diverse industry. This chapter concentrates on only that portion of welding safety related to the areas of light metal. You must read, learn, and follow all safety rules, regulations, and procedures for those areas.

Light welding fabrication, like all other areas of welding work, has a number of potential safety hazards. These

hazards need not result in anyone being injured. Learning to work safely is as important as learning to be a skilled welding fabrication worker.

You must approach new jobs with your safety in mind. Your safety is your own responsibility, and you must take on that responsibility. It is not possible to anticipate all of the possible dangers in every job. There may be some dangers not covered in this text. You can get specific safety information from welding equipment manufacturers and their local suppliers, your local college or university, and the Internet.

If an accident does occur on a welding site, it can have consequences far beyond just the person injured. Serious accidents can result in local, state, or national investigations. For example, if the federal office of the Occupational Safety and Health Administration (OSHA) becomes involved, then the job site may be closed for hours, days, weeks, months, or even permanently. While the job site is closed for the investigation, you may be off without pay. If it is determined that your intentional actions contributed to the accident, you may lose your job, be fined, or worse. Always follow the rules, and never engage in horseplay or play "practical jokes" while at work.

Specific safety information for each of the welding processes covered in this textbook are included in the chapters that contain those welding processes.

BURN CLASSIFICATION

Burns are one of the most common and painful injuries that occur in the welding shop. Burns can be caused by ultraviolet (UV) light rays as well as by contact with hot welding material. The chance of infection is high with burns because of the dead tissue. It is important that all burns receive proper medical treatment to reduce the chance of infection.

Burns are divided into three classifications depending on the degree of severity. The three classifications include first-degree, second-degree, and third-degree burns. Whether burns are caused by hot material or by light, they can be avoided if proper clothing and other protective gear are worn.

First-Degree Burns

First-degree burns occur when the surface of the skin is reddish in color, tender, and painful and there is no involvement of any broken skin; these can occur at temperatures of approximately 130°F (55°C). The first step in treating a first-degree burn is to immediately put the burned area under cold water (not iced) or apply cold water compresses (clean lint-free towel, washcloth, or handkerchief soaked in cold water) until the pain decreases. Then, cover the area with sterile bandages or a clean cloth. Do not apply butter or grease. Do not apply any other home remedies or medications without a doctor's recommendation, **Figure 2-1**.

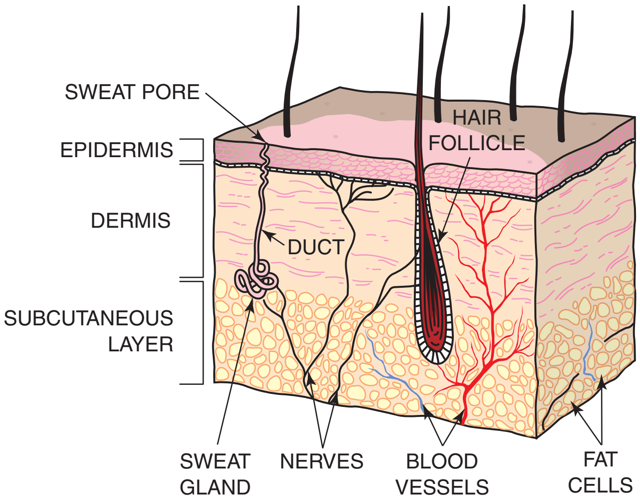


FIGURE 2-1 First-degree burn. Only the skin surface (epidermis) is affected.

Second-Degree Burns

Second-degree burns occur when the surface of the skin is severely damaged, resulting in the formation of blisters and possible breaks in the skin; these will occur when the skin is exposed to temperatures higher than 130°F (55°C). Again, the most important first step in treating a second-degree burn is to put the area under cold water (not iced) or apply cold water compresses until the pain decreases. Gently pat the area dry with a clean lint-free towel, and cover the area with a sterile bandage or clean cloth to prevent infection. Seek medical attention. If the burns are around the mouth or nose or involve singed nasal hair, then breathing problems may develop. Do not apply ointments, sprays, antiseptics, or home remedies. In an emergency, any cold liquid you drink—for example, water or cold tea—can be poured on a burn. The purpose is to lower the skin temperature as quickly as possible to reduce tissue damage, **Figure 2-2**.

Third-Degree Burns

Third-degree burns occur when the surface of the skin and possibly the tissue below the skin appear white or charred; these will occur at approximately 480°F (250°C). Initially, there may be little pain present because nerve endings have been destroyed. Do not remove any clothes that are stuck to the burn. Do not put ice water or ice on the burns; this could intensify the shock reaction. Do not apply ointments, sprays, antiseptics, or home remedies to burns. If the victim is on fire, smother the flames with a blanket, rug, or jacket. Breathing difficulties are common with burns around the face, neck, and mouth; be sure

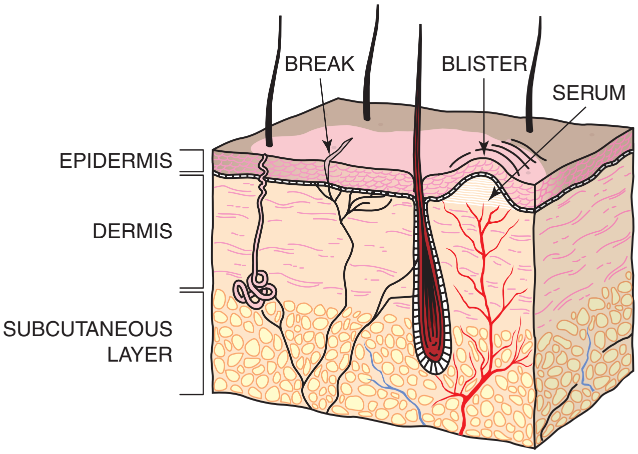


FIGURE 2-2 Second-degree burn. The epidermal layer is damaged, forming blisters or shallow breaks.

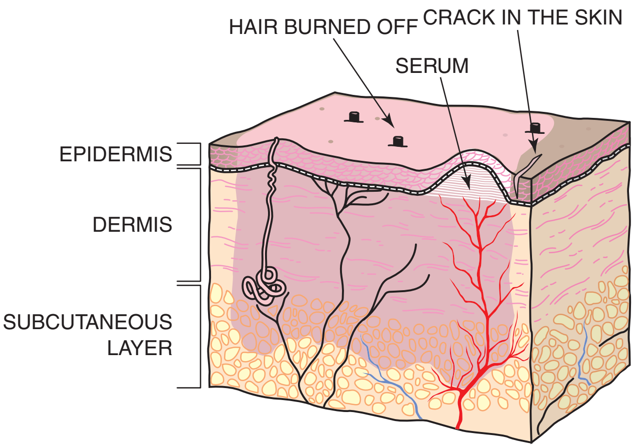


FIGURE 2-3 Third-degree burn. The epidermis, dermis, and the subcutaneous layers of tissue are destroyed.

that the victim is breathing. Place a cold cloth or cool (not iced) water on burns of the face, hands, or feet to cool the burned areas. Cover the burned area with thick, sterile, nonfluffy dressings. Call for an ambulance immediately; people with even small third-degree burns need to consult a doctor, **Figure 2-3**.

Burns Caused by Light

Some types of light can cause burns. The three types of light include ultraviolet, infrared, and visible. Ultraviolet and infrared are not visible to the unaided human eye. They are types of light that can cause burns. During welding, one or more of the three types of light may be present. Arc welding produces all three types of light, but gas welding produces visible and **infrared light** only.

The light from the welding process can be reflected from walls, ceilings, floors, or any other large surface. This reflected light is as dangerous as direct welding light. To reduce the danger from reflected light, the welding area, if possible, should be painted with a flat, dark-colored or black paint. Flat black will reduce the reflected light by absorbing more of it than any other color. When the welding is to be done on a job site, in a large shop, or in another area that cannot be painted, weld curtains can be placed to absorb the welding light, **Figure 2-4**. These special portable welding curtains may be either transparent or opaque. Transparent welding curtains are made of a special high-temperature, flame-resistant plastic that will prevent the harmful light from passing through.

Frommelt Safety Products

FIGURE 2-4 Portable welding curtains.

CAUTION

Welding curtains must always be used to protect other workers in the area who might be exposed to the welding light.

Visible Light Visible light is the light that we see. It is produced in varying quantities and colors during welding. Too much **visible light** may cause temporary night blindness (poor eyesight under low light levels). Too little visible light may cause eyestrain, but visible light is not hazardous.

Infrared Light Infrared light is the light wave that is felt as heat. Although infrared light can cause burns, a person will immediately feel this type of light. Therefore, burns

can easily be avoided. When you are welding you feel infrared light, and you are probably being exposed to **ultraviolet light** at the same time; therefore, protective action should be taken to cover yourself.

Ultraviolet Light Ultraviolet light waves are the most dangerous. They can cause first-degree and second-degree burns to a welder's exposed skin or eyes. Because a welder cannot see or feel ultraviolet light while being exposed to it, the welder must stay protected when in the area of any of the arc welding processes. The most common areas that get burned by UV are the welder's neck and wrist. If the top button is not fastened on your shirt or welding jacket, then the unexposed skin is in a direct line of the arc. When welders do not use gauntlet-type welding gloves, their wrists are not protected. Because of the closeness to the arc, the wrist can be burned very quickly. In both cases it is later that evening or the next day before you realize you were burned. Ultraviolet light can also pass through loosely woven clothing, thin clothing, light-colored clothing, and damaged or poorly maintained arc welding helmets.

The distance from the arc is a major factor in the length of time that it may take to cause a burn, because the further you are from the arc the more diffused the light becomes. However, anyone working or walking through a welding area must take safeguards by using appropriate PPE.

The ultraviolet light is so intense during some welding processes, such as CAC-A, GTAW, and GMAW, where the arc is not diffused by the gaseous cloud formed by the flux, producing higher levels of light radiation than SMAW or FCAW, that a welder's eyes can receive a **flash burn** within seconds, and the skin can be burned within minutes.

Ultraviolet light can burn the eye in two ways. This light can injure either the white of the eye or the retina, which is the back of the eye. Burns on the retina are not painful but may cause some loss of eyesight. The whites of the eyes can also be burned by ultraviolet light, **Figure 2-5**. The whites of the eyes are very sensitive, and burns are very painful. The eyes are easily infected because, as with any burn, many cells are killed. These dead cells in the moist environment of the eyes will promote the growth of bacteria that cause infection if not properly treated. When the eye is burned, it feels as though there is something in the eye. Without a professional examination, however, it is impossible to tell the difference. Any time you receive an eye injury, you should see a doctor.

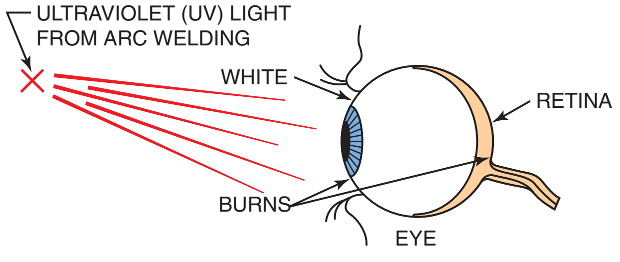


FIGURE 2-5 The eye can be burned on the white part or on the retina by ultraviolet light.

PERSONAL PROTECTION EQUIPMENT (PPE)

Personal protection equipment is commonly referred to as PPE. **Figure 2-6** illustrates the most commonly used PPE for welding. However, PPE must be selected based on the level of protection required. For example, in a general work area the level of PPE might only be **safety glasses**, whereas a welding shop area will require a higher level of protection. The following section provides guidance and should be used along with your company's and supervisor's guidelines so you will know which PPE you may need to work safely.

Signs must be posted designating the shop or other area where welding, grinding, or other operations will be performed and stating that safety glasses or other eye protection and appropriate PPE must be worn by everyone in the area. Safety glasses must even be worn under welding helmets at all times.

General Work Clothing

Special protective clothing cannot be worn at all times. Therefore, it is important to choose general work clothing that will minimize the possibility of getting burned because of the high temperature and amount of hot sparks, metal, and slag produced during welding, cutting, or brazing.

Work clothing must also stop ultraviolet light from passing through it. This is accomplished if the material chosen is a dark color, thick, and tightly woven. The best choice is 100% wool, but it is difficult to find. Another good choice is 100% cotton clothing, which is the most popular fabric used.

You must avoid wearing synthetic materials, including nylon, rayon, and polyester. They can easily melt or catch fire. Some synthetics produce a hot, sticky residue that can make burns more severe. Others may produce poisonous gases.

The following are some guidelines for selecting work clothing:

- Shirts must have long sleeves to protect the arms, must have a high-buttoned collar to protect the neck, **Figure 2-7**, must be long enough to tuck into the pants to protect the waist, and must have flaps on the pockets to keep sparks out (or have no pockets).
- Pants must have legs long enough to cover the tops of the boots and must be without cuffs that would catch sparks.
- Boots must have high tops to keep out sparks, must have steel toes to prevent crushed toes, **Figure 2-8**, and must have smooth tops to prevent sparks from being trapped in seams.
- Caps should be thick enough to prevent sparks from burning the top of a welder's head.

FIGURE 2-6 Typical welding PPE.

FIGURE 2-7 The top button of the shirt worn by the welder should always be buttoned to avoid severe burns to that person's neck.

FIGURE 2-8 Safety boots with steel toes are required by many welding shops.

All clothing must be free of frayed edges and holes. The clothing must be relatively tight-fitting to prevent excessive folds or wrinkles that might trap sparks.

Some welding clothes have pockets on the inside to prevent the pockets from collecting sparks. However, it is not safe to carry butane lighters or matches in these or any pockets while welding. Lighters and matches can easily catch fire or explode if they are subjected to the heat and sparks of welding.

CAUTION

Damage to your hearing caused by high sound levels may not be detected until later in life, and the resulting loss in hearing is permanent. Your hearing will not improve with time, and each exposure to high levels of sound will further damage your hearing.

Special Protective Clothing

General work clothing is worn by each person in the shop. In addition to this clothing, extra protection is needed for each person who is in direct contact with hot materials. Leather is often the best material to use because it is lightweight, flexible, resists burning, and readily available. Synthetic insulating materials are also available. Ready-to-wear leather protection includes capes, jackets, aprons, sleeves, gloves, caps, pants, knee pads, and spats, among other items.

Hand Protection All-leather, gauntlet-type gloves should be worn when doing any welding, **Figure 2-9**. Gauntlet

Larry Jeffus

FIGURE 2-9 All leather, gauntlet-type, welding gloves.

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FIGURE 2-10 For welding that requires a great deal of manual dexterity, soft leather gloves can be worn.

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FIGURE 2-11 Full leather jacket.

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FIGURE 2-12 Full leather sleeve.

gloves that have a cloth liner for insulation are best for hot work. Noninsulated gloves will give greater flexibility for fine work. Some leather gloves are available with a canvas gauntlet top, which should be used for light work only.

When a great deal of manual dexterity is required for gas tungsten arc welding, brazing, soldering, oxyfuel gas welding, and other delicate processes, soft leather gloves may be used, **Figure 2-10**. All-cotton gloves are sometimes used when doing very light welding.

Body Protection Full leather jackets and capes will protect a welder's shoulders, arms, and chest, **Figure 2-11**. A jacket, unlike the cape, protects a welder's back and complete chest. A cape is open and much cooler but offers less protection. The cape can be used with a bib apron to provide some additional protection while leaving the back cooler. Either the full jacket or the cape with a bib apron should be worn for any out-of-position work.

Bib Aprons or Full Aprons will protect a welder's lap. Welders will especially need to protect their laps if they squat or sit while working and when they bend over or lean against a table.

Arm Protection For some vertical welding, a full or half sleeve can protect a person's arm, **Figure 2-12**. The

sleeves work best if the work level is not above the welder's chest. Work levels higher than this usually require a jacket or cape to keep sparks off the welder's shoulders.

Leg and Foot Protection When heavy cutting or welding is being done and a large number of sparks are falling, leather pants and spats should be used to protect the welder's legs and feet. If the weather is hot and full leather pants are uncomfortable, then leather aprons with leggings are available. Leggings can be strapped to the legs, leaving the back open. Spats will prevent sparks from burning through the front of lace-up boots.

Face and Eye Protection

Eye protection must be worn in the shop at all times. Eye protection can be **safety glasses** with side shields, **Figure 2-13**, **goggles**, or a **full face shield**. To provide better protection when working in brightly lit areas or outdoors, some welders wear **flash glasses**, which are special lightly tinted safety glasses. Flash safety glasses provide protection from both flying debris and reflected light. Do not use sunglasses for safety glasses because they will not provide impact safety from flying debris or UV light protection, and they will not meet OSHA standards for welding shop eye ware.

Wearing eye protection at all times while in a welding shop that will prevent UV burns is important because UV exposure can go undetected, because it is happening with the symptoms not showing up until the next day. In that way it is much like a sunburn that is not felt until the following day.

Welders must take appropriate precautions in selecting filters or goggles that are suitable for the process being used. Selecting the correct shade lens is also important because both extremes of too light or too dark can cause eyestrain. New welders often select too dark a lens, assuming it will give them better protection, but this results in eyestrain in the same manner as if they were trying to read in a poorly lit room. In reality, any approved arc welding lenses will filter out the harmful ultraviolet light. Select a lens that lets you see comfortably. At the very least, the welder's eyes must not be strained by excessive glare from the arc.

Goggles

Ventilated goggles that are vented adequately to prevent fogging and have lenses that meet ANSI Z87 standards can be worn in place of safety glasses. Goggles may also be worn over prescription glasses when the prescription glasses lenses do not meet the ANSI standards.

Full Face Shield

Safety glasses with side shields are adequate for general use; however, for heavy grinding, chipping, or overhead work, a full face shield should be worn in addition to safety glasses, **Figure 2-14**. Tented full face shields are available that meet the filter lenses requirements for OFC, OFW, and low current processes such as micro plasma arc cutting, where UV radiation exposure does not exist.

Welding Helmets

Even with quality **welding helmets**, like that shown in **Figure 2-15**, the welder must check for potential problems that may occur from accidents or daily use. Small, undetectable leaks of ultraviolet light in an arc welding helmet can cause a welder's eyes to itch or feel sore after a day of welding. To prevent these leaks, make sure the lens gasket is installed correctly, **Figure 2-16**. The outer and inner clear lens must be plastic. As shown in **Figure 2-17**, the lens can be checked for cracks by twisting it between your fingers. Worn or cracked spots on a helmet must be repaired. Tape can be used as a temporary repair until the helmet can be replaced or permanently repaired.

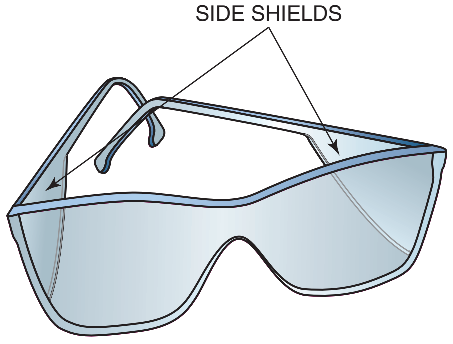

FIGURE 2-13 Safety glasses with side shields.

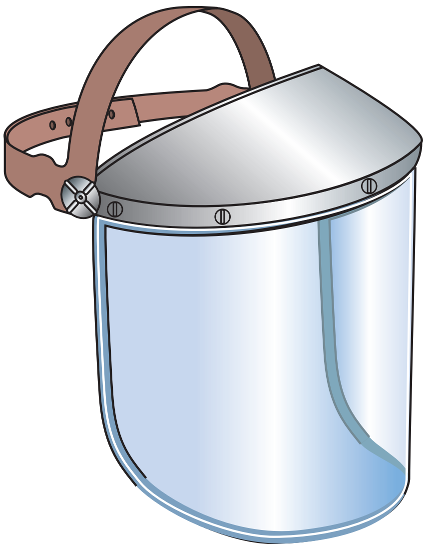

FIGURE 2-14 Full face shield.

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FIGURE 2-15 Typical arc welding helmets used to provide eye and face protection during welding.

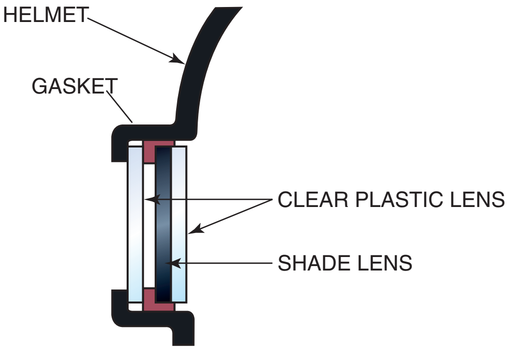


FIGURE 2-16 The correct placement of the gasket around the shade lens is important because it can stop ultraviolet light from bouncing around the lens assembly.

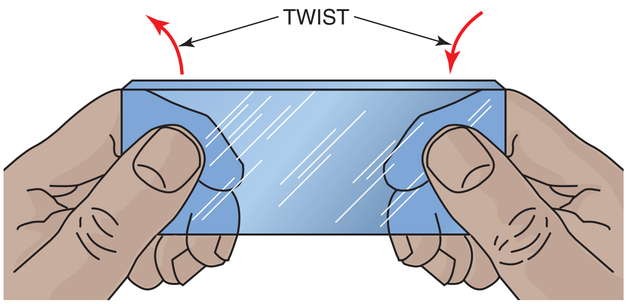


FIGURE 2-17 To check the shade lens for possible cracks, gently twist it.

Auto Darkening Welding Helmets

Auto darkening welding helmets can be a tremendous help for new welders because they let you see where your electrode is and darken for welding within 1/20,000 of a second. These helmets are available with a number of different features such as:

- Auto Off—This feature helps to save the batteries. Some helmets use standard AA or AAA batteries so replacing dead batteries is easy and not too costly, but others use watch-type batteries, which will die quickly if left on and are somewhat pricey to replace.
- Solar Panel—These panels will help keep the helmet charged with the light from the arc.
- Multifunction—Some helmets can be set to allow them to be used for grinding, gas welding, and arc welding. These helmets can replace full face shields and gas welding goggles.
- Sensors—The number of sensors on helmets vary from one or two to many more. The more sensors a helmet has, the less likely that the lens would not darken if you are welding in a restricted area where the sensors may be shaded from the arc light.
- Knobs and Switches—The size and location of the knobs used to adjust the sensitivity and darkening shade can be on the outside or inside of the helmet. The location can make it easier or difficult to adjust with gloves on. The same thing applies to the on–off switch.
- Weight—The weight of the auto darkening helmets vary greatly and often vary based on price as much as anything else.
- Lens Size—Affect the viewing area and can vary greatly between different helmets.

Shop Noise

The welding environment can be very noisy. The sound level is at times high enough to cause pain and some loss of hearing if the welder's ears are unprotected. **Table 2-1** lists some of the common welding shop sources of noise along with the recommended maximum time of exposure for unprotected ears. Note that the higher the sound levels, the shorter the acceptable time of exposure. In addition to the sound levels, the frequency of the sound will affect how it is perceived, **Figure 2-18** (**Noise**).

PROCESS	TYPICAL SOUND LEVELS	MAXIMUM TIME AT MAXIMUM LEVEL
GTAW	up to 75 dB(A)	8 hours
SMAW	85-95 dB(A)	4 hours
OFG	95 dB(A)	4 hours
OFC	up to 100 dB(A)	2 hours
GMAW	95-102 dB(A)	1 hour
Grinding	95-105 dB(A)	1 hour
PAC	98-105 dB(A)	1 hour
Chipping	105 dB(A)	1 hour
CAC-A	100-115 dB(A)	15 minutes

TABLE 2-1 Maximum Sound Level Exposure

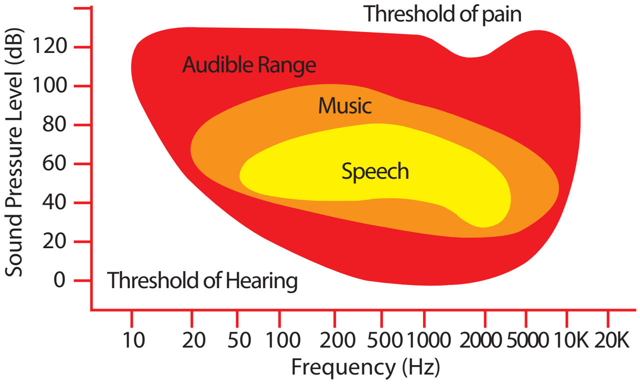


FIGURE 2-18 How sound is perceived.

Ear Protection Ear protection is available in several forms. One form of protection is **earmuffs** that cover the outer ear completely, **Figure 2-19**. Another form of protection is **earplugs** that fit into the ear canal, **Figure 2-20**. Both of these protect a person's hearing, but only the earmuffs protect the outer ear from burns.

CAUTION

Welding or cutting must never be performed on drums, barrels, tanks, vessels, or other containers until they have been emptied and cleaned thoroughly, eliminating all flammable materials and all substances (such as detergents, solvents, greases, tars, or acids) that might produce flammable, toxic, or explosive vapors when heated.

Courtesy of MSA

FIGURE 2-19 Earmuffs provide complete ear protection and can be worn under a welding helmet.

Courtesy of MSA

FIGURE 2-20 Earplugs used as protection from noise only.

Respiratory Protection

All welding and cutting processes produce undesirable by-products, such as harmful dusts, fogs, fumes, mists, gases, smokes, sprays, or vapors. For your safety and the safety of others, your primary objective will be to prevent these contaminants from forming and collecting in the shop atmosphere. This will be accomplished as much as possible by engineering and design control measures such as water tables for cutting, general and local **ventilation**, thorough cleaning of surface contaminants before starting work, and confinement of the operation to outdoor or open spaces.

Production of welding by-products cannot be avoided. They are created when the temperature of metals and fluxes is raised above the temperatures at which they vaporize or decompose. Most of the by-products are recondensed in the weld. However, some do escape into the atmosphere, producing the haze that occurs in improperly ventilated welding shops. Some fluxes used in welding electrodes produce fumes that may irritate the welder's nose, throat, and lungs.

When welders must work in an area where effective general controls to remove airborne welding by-products are not feasible, respirators shall be provided by their employers when this equipment is necessary to protect their health. The respirators supplied by the welding shop must be applicable and suitable for the purpose intended. Where respirators are necessary to protect welders' health or whenever respirators are required by the welding shop, the shop will establish and implement a written respiratory protection program with worksite-specific procedures. Welders are responsible for following the welding shop's established written respiratory protection program. Guidelines for the respiratory protection program are available from the Occupational Safety and Health Administration (OSHA) office in Washington, DC.

Respirator Training Training must be a part of the welding shop's respiratory protection program. This training should include instruction on any and/or all of the following procedures for

- proper use of respirators, including techniques for putting them on and removing them,
- schedules for cleaning, disinfecting, storing, inspecting, repairing, discarding, and performing other aspects of maintenance of the respiratory protection equipment,
- selection of the proper respirators for use in the workplace and any respiratory equipment limitations,
- procedures for testing the proper fitting of respirators,
- proper use of respirators in both routine and reasonably foreseeable emergency situations, and
- regular evaluation of the effectiveness of the program.

Respirator Equipment All respiratory protection equipment used in a welding shop should be certified by the National Institution for Occupational Safety and Health (NIOSH). Some of the types of respiratory protection equipment that may be used are the following:

- Air-purifying respirators have an air-purifying filter, cartridge, or canister that removes specific air contaminants by passing ambient air through the air-purifying element.
- Atmosphere-supplying respirators supply breathing air from a source independent of the ambient atmosphere; this includes both the supplied-air respirators (SARs) and self-contained breathing apparatus (SCBA) units.
- Demand respirators are atmosphere-supplying respirators that admit breathing air to the facepiece only when a negative pressure is created inside the facepiece by inhalation.
- Positive pressure respirators are respirators in which the pressure inside the respiratory inlet covering exceeds the ambient air pressure outside the respirator.
- Powered air-purifying respirators (PAPRs) are air-purifying respirators that use a blower to force the ambient air through air-purifying elements to the inlet covering, **Figure 2-21**.
- Self-contained breathing apparatuses (SCBAs) are atmosphere-supplying respirators for which the breathing air source is designed to be carried by the user.
- Supplied-air respirators (SARs), or airline respirators, are atmosphere-supplying respirators for which the source of breathing air is not designed to be carried by the user.

FIGURE 2-21 Filtered fresh air is forced into the welder's breathing area.


Courtesy of MSA

FIGURE 2-22 Typical respirator for contaminated environments. The filters can be selected for specific types of contaminant.

Respiratory protection equipment used in many welding applications is of the filtering facepiece (dust mask) type, **Figure 2-22**. These mask types use the negative pressure as you inhale to draw air through a filter, which is an integral part of the facepiece. In areas of severe contamination you may use a hood-type respirator, which covers your head and neck and may even cover portions of your shoulders and torso.

Fume Sources Some materials that can cause respiratory problems are used as paints, coating, or plating on metals to prevent rust or corrosion. Other potentially hazardous materials might be used as alloys in metals to give them special properties.

Before welding or cutting, any metal that has been painted or has any grease, oil, or chemicals on its surface must be thoroughly cleaned. This cleaning may be done by grinding, sandblasting, or applying an approved solvent. Metals that are plated or alloyed may not be able to be cleaned before welding or cutting begins.

Most paints containing lead have been removed from the market. But some industries, such as marine or ship applications, still use these lead-based paints. Often old machinery and farm equipment surfaces still have lead-based paint coatings. Solder often contains lead alloys. The welding and cutting of lead-bearing alloys or metals whose surfaces have been painted with lead-based paint can generate lead oxide fumes. Inhalation and ingestion of lead oxide fumes and other lead compounds will cause lead poisoning. Symptoms include a metallic taste in the mouth, loss of appetite, nausea, abdominal cramps, and insomnia. In time, anemia and general weakness, chiefly in the muscles of the wrists, develop.

Cadmium Cadmium is a plating material often used on bolts, nuts, hinges, and other hardware items, and it gives the surface a yellowish-gold appearance. Acute exposure to high concentrations of cadmium fumes can produce severe lung irritation. Long-term exposure to low levels of cadmium in air can result in emphysema (a disease affecting the lung's ability to absorb oxygen) and can damage the kidneys.

Zinc Zinc is another plating material that is often in the form of galvanizing; it may be found on pipes, sheet metal, bolts, nuts, and many other types of hardware. Zinc plating that is thin may appear as a shiny, metallic patchwork or crystal pattern; thicker, hot-dipped zinc appears rough and may look dull. Zinc is used in large quantities in the manufacture of brass and is found in brazing rods. Inhalation of zinc oxide fumes can occur when welding or cutting on these materials. Exposure to these fumes is known to cause metal fume fever; its symptoms are very similar to those of common influenza.

Some concern has been expressed about the possibility of lung cancer being caused by some of the chromium compounds that are produced when welding stainless steels.

CAUTION

Extreme care must be taken to avoid the fumes produced when welding is done on dirty or used metal. Any chemicals that are on the metal will become mixed with the welding fumes, a combination that can be extremely hazardous. All metal must be cleaned before welding to avoid this potential problem.

Rather than take chances, welders should recognize that fumes of any type, regardless of their source, should not be inhaled. The best way to avoid problems is to provide adequate ventilation. If this is not possible, then breathing protection should be used. Protective devices for use in poorly ventilated or confined areas are shown in Figure 2-21 and Figure 2-22.

Vapor Sources Potentially dangerous gases also can be present in a welding shop. Proper ventilation or respirators are necessary when welding in confined spaces, regardless of the welding process being used. Ozone is a gas that is produced by the ultraviolet radiation in the air in the vicinity of arc welding and cutting operations. Ozone is very irritating to all mucous membranes, with excessive exposure producing pulmonary edema, or fluid on the lung, making it difficult to breathe. Severe cases of pulmonary edema may require immediate care. Other effects of exposure to ozone include headache, chest pain, and dryness in the respiratory tract.

Phosgene is formed when ultraviolet radiation decomposes chlorinated hydrocarbon. Fumes from chlorinated hydrocarbons can come from solvents such as those used for degreasing metals and from refrigerants in air-conditioning systems. They decompose in the arc to produce a potentially dangerous chlorine acid compound. This compound reacts with the moisture in the lungs to produce hydrogen chloride, which in turn destroys lung tissue. For this reason, any use of chlorinated solvents should be well away from welding operations in which ultraviolet radiation or intense heat is generated. Any welding or cutting on refrigeration or air-conditioning piping must be done only after the refrigerant has been completely removed in accordance with Environmental Protection Agency (EPA) regulations.

Care also must be taken to avoid the infiltration of any fumes or gases, including argon or carbon dioxide, into a confined working space, such as when welding in tanks. The collection of some fumes and gases in a work area can go unnoticed by the welders. Concentrated fumes or gases can cause a fire or explosion if they are flammable, asphyxiation if they replace the oxygen in the air, or death if they are toxic.

Despite these fumes and other potential hazards in welding shops, welders have been found to be as healthy as workers employed in other industrial occupations.

VENTILATION

The actual welding area should be well-ventilated. Excessive fumes, ozone, or smoke may collect in the welding area; ventilation should be provided for their removal.

Natural Ventilation **Natural ventilation** is best, but forced ventilation may be required. Areas that have 10,000 cubic feet (283 cubic meters) or more per welder or that have ceilings 16 feet (4.9 meters) high or higher,

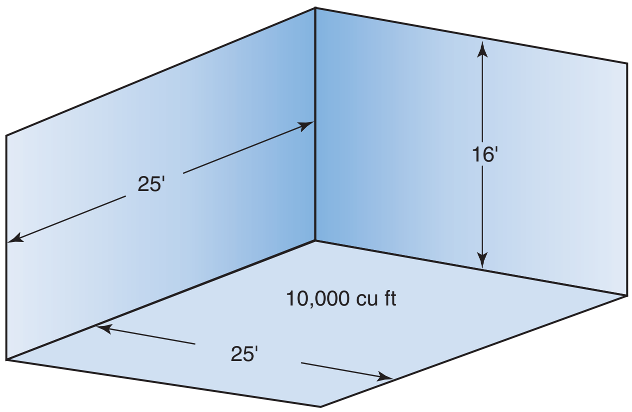


FIGURE 2-23 A room with a ceiling that is 16 ft. (4.9 m) high may not require forced ventilation for one welder.

Figure 2-23, may not require forced ventilation unless fumes or smoke begin to collect.

Forced Ventilation Small shops or shops with large numbers of welders require forced ventilation. **Forced ventilation** can be general or localized using fixed or flexible **exhaust pickups**, **Figure 2-24**. General room ventilation must be at a rate of 2000 cu ft (56 m^3) or more per person welding. Localized exhaust pickups must have a draft strong enough to provide 100 linear feet (30.5 m) per minute of air velocity pulling welding fumes away from the welder. Local, state, or federal regulations may require that welding fumes be treated to remove hazardous components before they are released into the atmosphere.

Any system of ventilation should draw the fumes or smoke away before it rises past the level of the welder's face.

Forced ventilation is always required when welding on metals that contain zinc, lead, beryllium, cadmium, mercury, copper, austenitic manganese, or other materials that give off dangerous fumes.

Larry Jeffus

FIGURE 2-24 An exhaust pickup.

THINK GREEN
Waste Material Disposal

Welding shops generate a lot of waste material. Much of the waste is scrap metal. All scrap metal, including electrode stubs, can easily be recycled. Green practices like recycling metal are good for the environment and can generate revenue for your welding shop.

Some of the other waste, such as burned flux, cleaning solvents, and dust collected in shop air filtration systems, may be considered hazardous material. Check with the material manufacturer or an environmental consultant to determine if any waste material is considered hazardous. Throwing hazardous waste material into the trash, pouring it on the ground, or dumping it down the drain is illegal. Before you dispose of any welding shop waste that is considered hazardous, you must first consult local, state, and/or federal regulations. Protecting our environment from pollution is everyone's responsibility.

SAFETY DATA SHEETS (SDSs)

All manufacturers of potentially hazardous materials must provide to the users of their products detailed information regarding possible hazards resulting from the use of their products. These **safety data sheets (SDS)** were formerly known as material safety data sheets (MSDS) They must be provided to anyone using the product or anyone working in the area where the products are in use. Often companies will post these sheets on a bulletin board or put them in a convenient place near the work area. Some states have right-to-know laws that require specific training of all employees who handle or work in areas with hazardous materials.

CAUTION

If you feel you have been injured while using a product, then you should, if possible, take the material's SDS with you when you are seeking medical treatment.

HANDLING AND STORING CYLINDERS

Oxygen and fuel gas cylinders or other flammable materials must be stored separately. The storage areas must be separated by 20 ft (6.1 m) or by a wall 5-ft high (1.5 m) with at least a 30-minute (min) burn rating, **Figure 2-25**. The purpose of the distance or wall is to keep the heat of a small fire from causing the oxygen cylinder safety valve to release. If the safety valve were to release the oxygen, then a small fire would become a raging inferno.

Inert gas cylinders may be stored separately or with oxygen cylinders. Empty cylinders must be stored separately

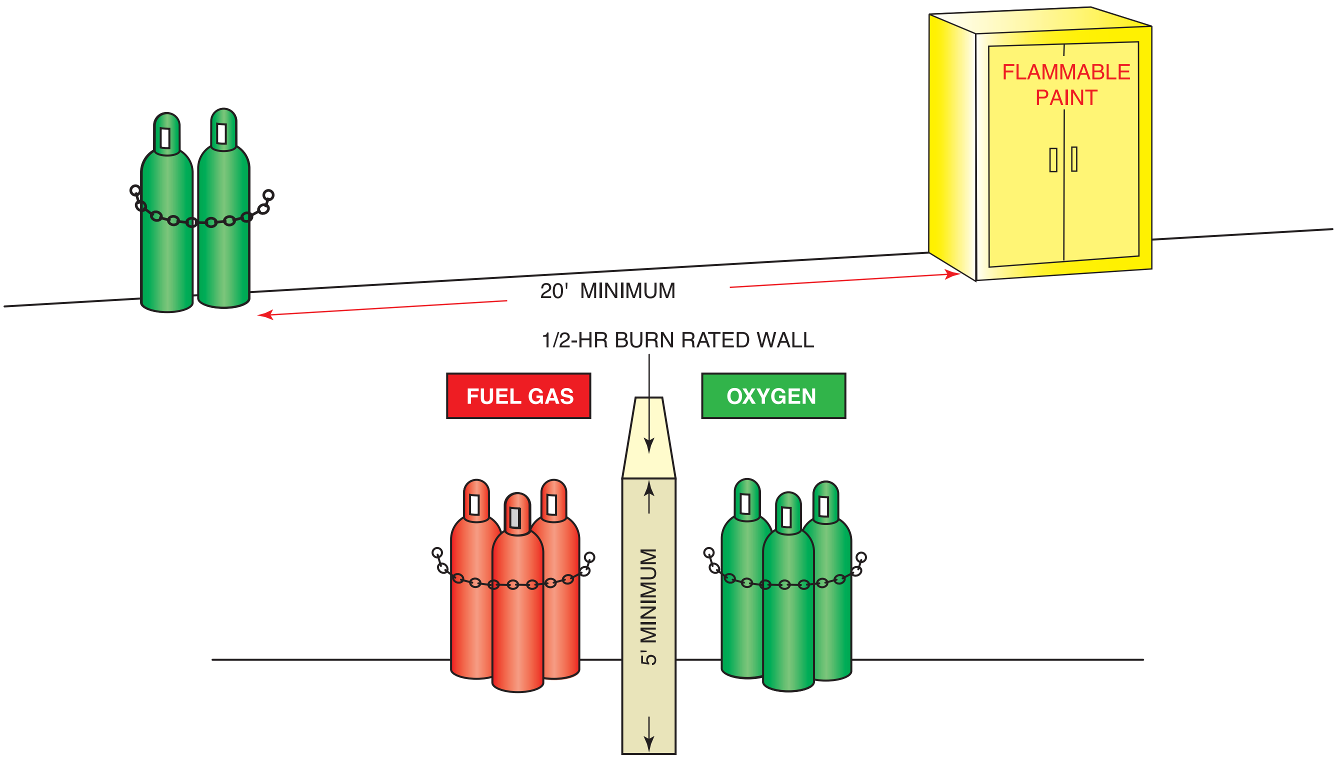


FIGURE 2-25 The minimum safe distance between stored fuel gas cylinders and any flammable material is 20 ft (6.1 m) or a wall 5 ft (1.5 m) high.

or with the same type of full cylinders in the same room or area. All cylinders must be stored vertically and have the protective caps screwed on firmly.

Securing Gas Cylinders

Cylinders must be secured with a chain or other device so that they cannot be knocked over accidentally. Cylinders attached to a manifold or stored in a special room used only for cylinder storage should be chained.

Storage Areas

Cylinder storage areas must be located away from halls, stairwells, and exits so that in case of an emergency they will not block an escape route. Storage areas should also be located away from heat, radiators, furnaces, and welding sparks. The location of storage areas should be such that unauthorized people cannot tamper with the cylinders. A **warning sign** that reads "Danger—No Smoking, Matches, or Open Lights," or similar wording, must be posted in the storage area, **Figure 2-26**.

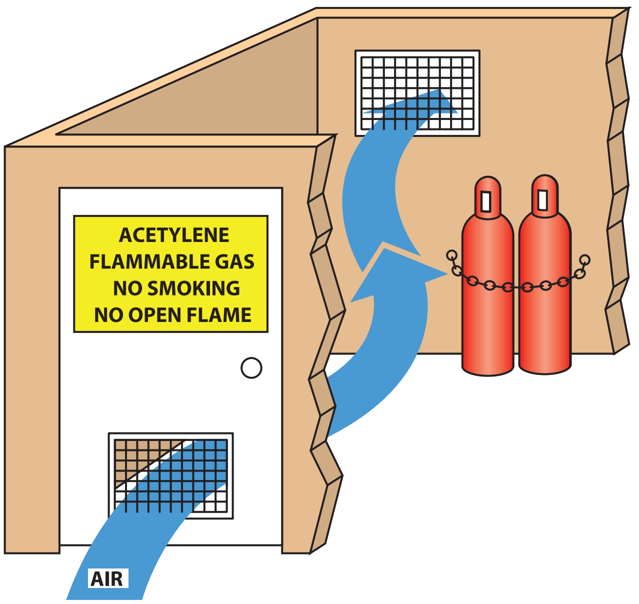


FIGURE 2-26 A separate room used to store acetylene must have good ventilation and should have a warning sign posted on the door.

Cylinders with Valve Protection Caps

Cylinders equipped with a **valve protection cap** must have the cap in place unless the cylinder is in use. The protection cap prevents the valve from being broken off if the cylinder is knocked over. If the valve of a full high-pressure cylinder (argon, oxygen, CO_2, or mixed gases) is broken off, then the cylinder can fly around the shop like a missile if it has not been secured properly.

Never lift a cylinder by the safety cap or the valve. The valve can easily break off or be damaged.

When moving cylinders, the valve protection cap must be on, especially if the cylinders are mounted on a truck or trailer for out-of-shop work. The cylinders must never be dropped or handled roughly.

General Precautions

Use warm water (not boiling) to loosen cylinders that are frozen to the ground. Any cylinder that leaks, has a bad

FIGURE 2-27 Move a leaking fuel gas cylinder out of the building or any work area. The pressure should be slowly released after posting a warning of the danger.

valve, or has damaged threads must be identified and reported to the supplier. A piece of soapstone can be used to write the problem on the cylinder. If the leak cannot be stopped by closing the cylinder valve, then the cylinder should be moved to a vacant lot or an open area. The pressure should then be slowly released after posting a warning sign, **Figure 2-27**.

Acetylene

Acetylene cylinders that have been lying on their sides must stand upright for four hours or more before they are used. The acetylene is absorbed in **acetone**, and the acetone is absorbed in a filler. The filler does not allow the liquid to settle back away from the valve very quickly, **Figure 2-28**.

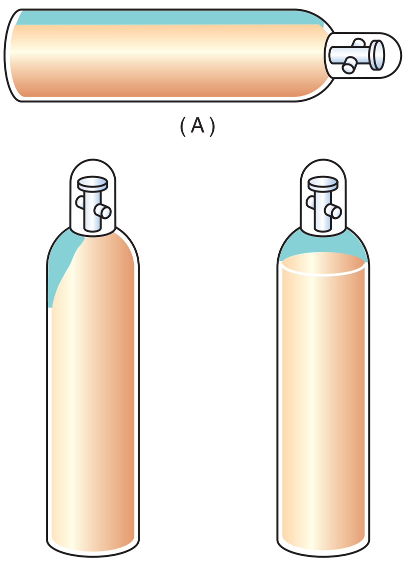


FIGURE 2-28 The acetone in an acetylene cylinder that has been laid on its side (A) must have time to settle away from the valve (B) before the cylinder can be used safely (C).

If the cylinder has been in a horizontal position, then using it too soon after it is placed in a vertical position may draw acetone out of the cylinder. Acetone lowers the flame temperature and can damage regulator or torch valve settings.

FIRE PROTECTION

Fire is a constant danger to the welder. Welding is considered to be "hot work" by the National Association of Fire Prevention. When performing welding outside of a shop, the welder may be required to obtain a hot work permit from the local fire marshal. During times when burn bans are in effect, performing hot work without a permit can be a violation of state or local laws. Even with a permit, welders can be held liable for any damage resulting from a fire caused by their welding. Highly combustible materials should be 35 ft (10.7 m) or more away from any welding. When it is necessary to weld within 35 ft (10.7 m) of combustible materials, when sparks can reach materials farther than 35 ft (10.7 m) away, or when anything more than a minor fire might start, a fire watch is needed.

Never weld outdoors when drought has resulted in a fire ban, **Figure 2-29**.

Fire Watch

A fire watch can be provided by any person who knows how to sound the alarm and use a fire extinguisher. The fire extinguisher must be the type required to put out a fire for the type of combustible materials near the welding. Combustible materials that cannot be removed from the welding area should be soaked with water or covered with sand or noncombustible insulating blankets, whichever is available.

Fire Extinguishers

The four types of fire extinguishers are type A, type B, type C, and type D. Each type is designed to put out fires on certain types of materials. Some fire extinguishers can be used on

FIGURE 2-29 You should not weld outside when the area is posted with a sign like this.

more than one type of fire. However, using the wrong type of fire extinguisher can be dangerous, causing the fire to spread, causing electrical shock, or causing an explosion.

Type A Extinguishers Type A extinguishers are used for combustible solids (articles that burn), such as paper, wood, and cloth. The symbol for a **type A fire extinguisher** is a green triangle with the letter *A* in the center, **Figure 2-30**.

Type B Extinguishers Type B extinguishers are used for combustible liquids, such as oil, gas, and paint thinner. The symbol for a **type B fire extinguisher** is a red square with the letter *B* in the center, **Figure 2-31**.

Type C Extinguishers Type C extinguishers are used for electrical fires. For example, they are used on fires involving motors, fuse boxes, and welding machines. The symbol for a **type C fire extinguisher** is a blue circle with the letter *C* in the center, **Figure 2-32**.

Type D Extinguishers Type D extinguishers are used on fires involving combustible metals, such as zinc, magnesium, and titanium. The symbol for a **type D fire extinguisher** is a yellow star with the letter *D* in the center, **Figure 2-33**.

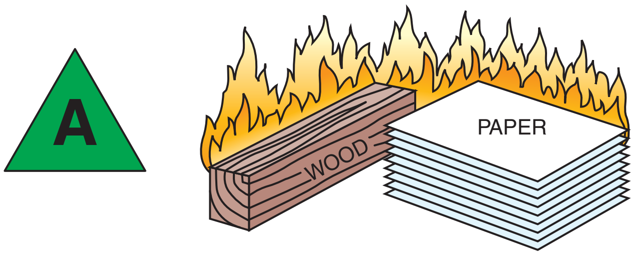


FIGURE 2-30 Type A fire extinguisher symbol.

FIGURE 2-31 Type B fire extinguisher symbol.

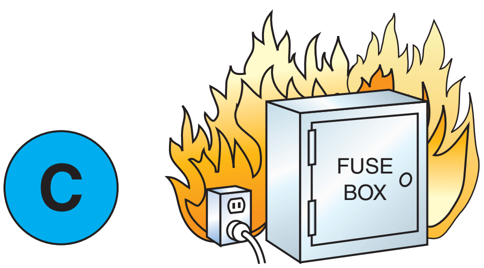


FIGURE 2-32 Type C fire extinguisher symbol.

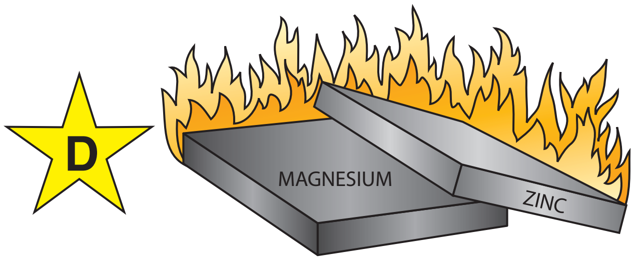


FIGURE 2-33 Type D fire extinguisher symbol.

Location of Fire Extinguishers

Fire extinguishers should be of a type that can be used on the types of combustible materials located nearby, **Figure 2-34**. The extinguishers should be placed so that they can be easily removed without reaching over combustible material. They should also be placed at a level low enough to be easily lifted off the mounting, **Figure 2-35**. The location of fire extinguishers should be marked with red paint and signs and high enough so that their location can be seen from a distance over people and equipment. The extinguishers should also be marked near the floor so that they can be found even if a room is full of smoke, **Figure 2-36**.

Using Fire Extinguishers

A fire extinguisher works by breaking the fire triangle of heat, fuel, and oxygen. Most extinguishers both cool the fire and remove the oxygen. They use a variety of materials

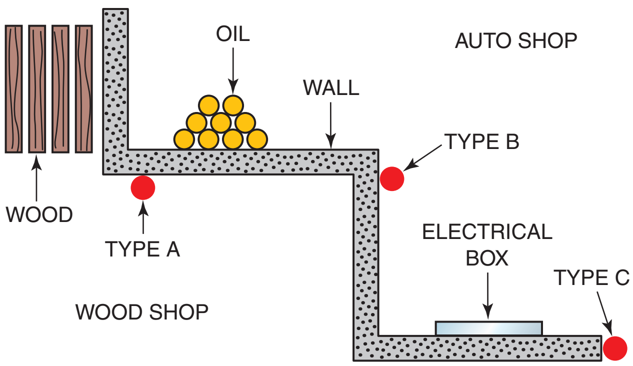


FIGURE 2-34 The type of fire extinguisher provided should be appropriate for the materials being used in the surrounding area.

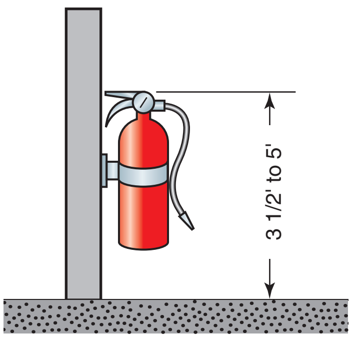


FIGURE 2-35 Mount the fire extinguisher so that it can be lifted easily in an emergency.

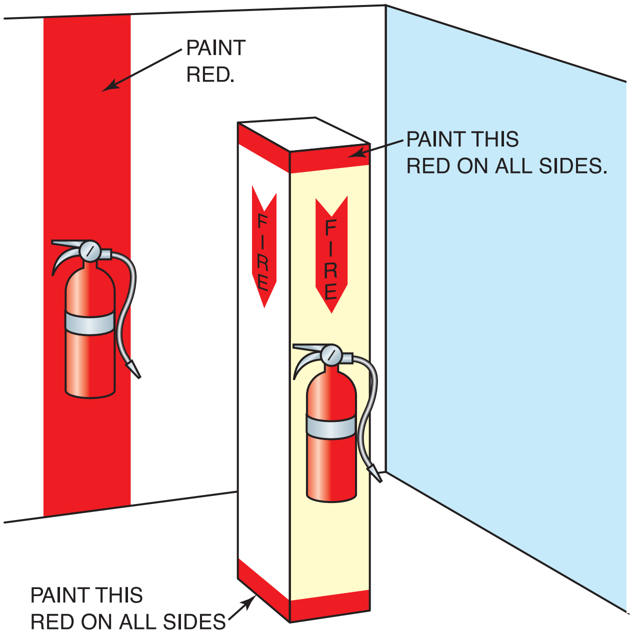


FIGURE 2-36 The location of fire extinguishers should be marked so they can be located easily in an emergency.

to extinguish the fire. The majority of fire extinguishers found in welding shops use foam, carbon dioxide, a pump tank, or dry chemicals.

When using a **foam** extinguisher, do not spray the stream directly into the burning liquid. Allow the foam to fall lightly on the base of the fire.

When using a **carbon dioxide** extinguisher, direct the discharge as close to the fire as possible, first at the edge of the flames and then gradually to the center.

When using a **dry chemical** extinguisher, direct the extinguisher at the base of the flames. In the case of type A fires, follow-up by directing the dry chemicals at the remaining material still burning. The extinguisher must be directed at the base of the fire where the fuel is located, **Figure 2-37**.

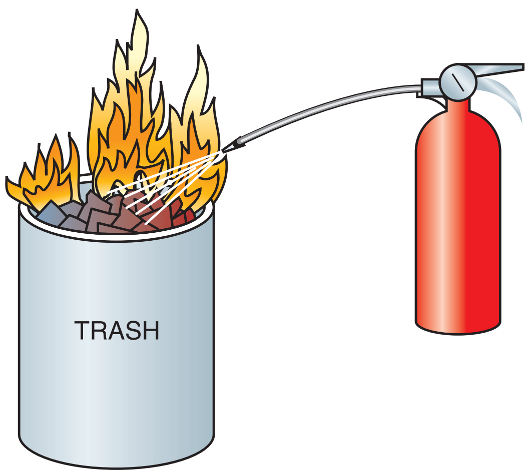


FIGURE 2-37 Point the extinguisher at the material burning, not at the flames.

EQUIPMENT MAINTENANCE

A routine schedule for planned maintenance (PM) of equipment will aid in detecting potential problems such as leaking coolant, loose wires, poor grounds, frayed insulation, or split hoses. Small problems, if fixed in time, can prevent the loss of valuable time due to equipment breakdown or injury.

Any maintenance beyond routine external maintenance should be referred to a trained service technician. In most areas, it is against the law for anyone but a licensed electrician to work on arc welders and for anyone but a factory-trained repair technician to work on regulators. Electrical shock and exploding regulators can cause serious injury or death.

Hoses

Hoses must be used only for the gas or liquid for which they were designed. Green hoses are to be used only for oxygen, and red hoses are to be used only for acetylene or other fuel gases. Using unnecessarily long lengths of hoses should be avoided. Never use oil, grease, or other pipe-fitting compounds on any joints. Hoses should also be kept out of the direct line of sparks. Any leaking or bad joints in gas hoses must be repaired.

WORK AREA CLEANING

The work area should be kept uncluttered and swept clean. Collections of steel, welding electrode stubs, wire, hoses, and cables are difficult to work around and easy to trip over. An electrode caddy can be used to hold the electrodes and stubs, **Figure 2-38**. Hooks can be made to hold hoses and cables, and scrap steel should be thrown into scrap bins.

FIGURE 2-38 An easy-to-build electrode caddy can be used to hold both electrodes and stubs.

THINK GREEN

Keep Outdoor Areas Clean

Keeping outdoor work areas swept clean of welding or cutting debris will prevent the debris from being washed away by rainwater. Some debris that is washed away may contaminate our streams and lakes.

Arc welding areas should be painted with a flat dark-colored or black finish to absorb as much of the ultraviolet light as possible. Portable screens should be used whenever arc welding is to be done outside of a welding booth.

If a piece of hot metal is going to be left unattended, then write the word *hot* on it before leaving. This procedure can also be used to warn people of hot tables, vises, firebricks, and tools.

HAND TOOLS

Hand tools are used by the welder to do necessary assembly and disassembly of parts for welding as well as to perform routine equipment maintenance.

The adjustable wrench is the most popular tool used by the welder. When using this wrench, it should be adjusted tightly on the nut and pushed so that most of the force is on the fixed jaw, **Figure 2-39**. When a wrench is being used on a tight bolt or nut, the wrench should be pushed with the palm of an open hand or pulled to prevent injuring the hand. If a nut or bolt is too tight to be loosened with a wrench, then obtain a longer wrench. A cheater bar should not be used.

The fewer points a box end wrench or socket has, the stronger it is and the less likely it is to slip or damage the nut or bolt, **Figure 2-40**.

Striking a hammer directly against a hard surface such as another hammer face or anvil may result in chips flying off and causing injury.

The mushroomed heads of chisels, punches, and the faces of hammers should be ground off, **Figure 2-41**. Chisels and punches that are going to be hit harder than a slight tap should be held in a chisel holder or with pliers to eliminate the danger of injuring your hand.

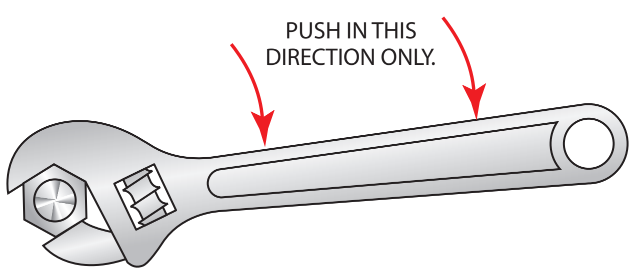


FIGURE 2-39 The adjustable wrench is stronger when used in the direction indicated.

Larry Jeffus

FIGURE 2-40 The fewer the points, the less likely the wrench is to slip.

Larry Jeffus

FIGURE 2-41 Any mushroomed heads must be ground off.

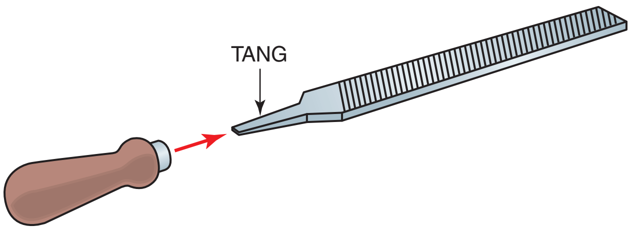


FIGURE 2-42 To protect yourself from the sharp tang of a file, always use a handle with a file.

A handle should be placed on the tang of a file to avoid injuring your hand, **Figure 2-42**. A file can be kept free of chips by rubbing a piece of soapstone on it before it is used.

It is important to remember to use the correct tool for the job. Do not try to force a tool to do a job it was not designed to do.

Hand Tool Safety

Hand tools used in welding fabrication should be treated properly and not abused. Many accidents can be avoided

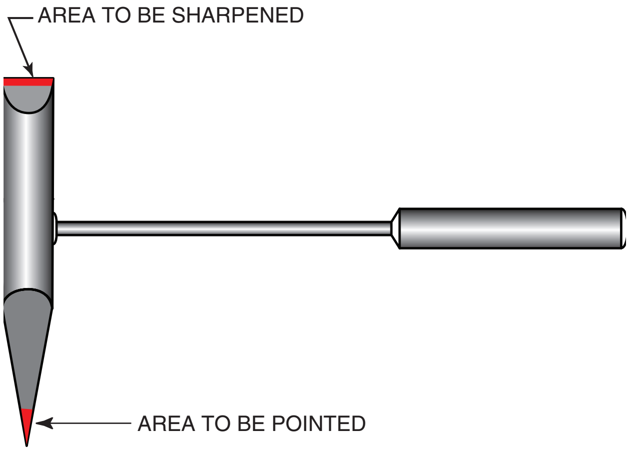


FIGURE 2-43 Welder's chipping hammers work best and are safer to use if the head is sharpened periodically.

by using the right tool for the job. For instance, use a tool that is the correct size for the work rather than one that is too large or too small.

Keep hand tools clean to protect them against the damage caused by corrosion. Wipe off any accumulated dirt, mud, and grease. Occasionally dip the tools in cleaning fluids or solvents and wipe them clean. Lubricate adjustable and other moving parts to prevent wear and misalignment.

Make sure that hand tools are sharp, **Figure 2-43**. Sharp tools make work easier, improve the accuracy of the work, save time, and are safer than dull tools. When sharpening, redressing, or repairing tools, shape, grind, hone, file, fit, and set them properly using other tools suited to each purpose. For sharpening tools, either an oilstone or a grindstone is preferred. If grinding on an abrasive wheel is required, then grind only a small amount at a time. Hold the tool lightly against the wheel to prevent overheating, and frequently dip the part being ground in water to keep it cool. This will protect the hardness of the metal and help to retain the sharpness of the cutting edge. Be sure to wear safety goggles when sharpening or redressing tools.

When carrying tools, protect the cutting edges and carry the tools in such a way that you will not endanger yourself or others. Carry pointed or sharp-edged tools in pouches or holsters.

Hammer Safety

Keep hammer handles secure and safe. Check wedges and handles frequently. Be sure heads are wedged tightly on handles. Keep handles smooth and free of rough or jagged edges. Do not rely on friction tape (electrical, duct, or masking tape) to secure split handles or to prevent handles from splitting. Replace handles that are split or chipped or that cannot be refitted securely.

When swinging a hammer, be absolutely certain that no one is within range or can come within range of the swing or be struck by flying material. Always allow plenty of room for arm and body movements when hammering on anything.

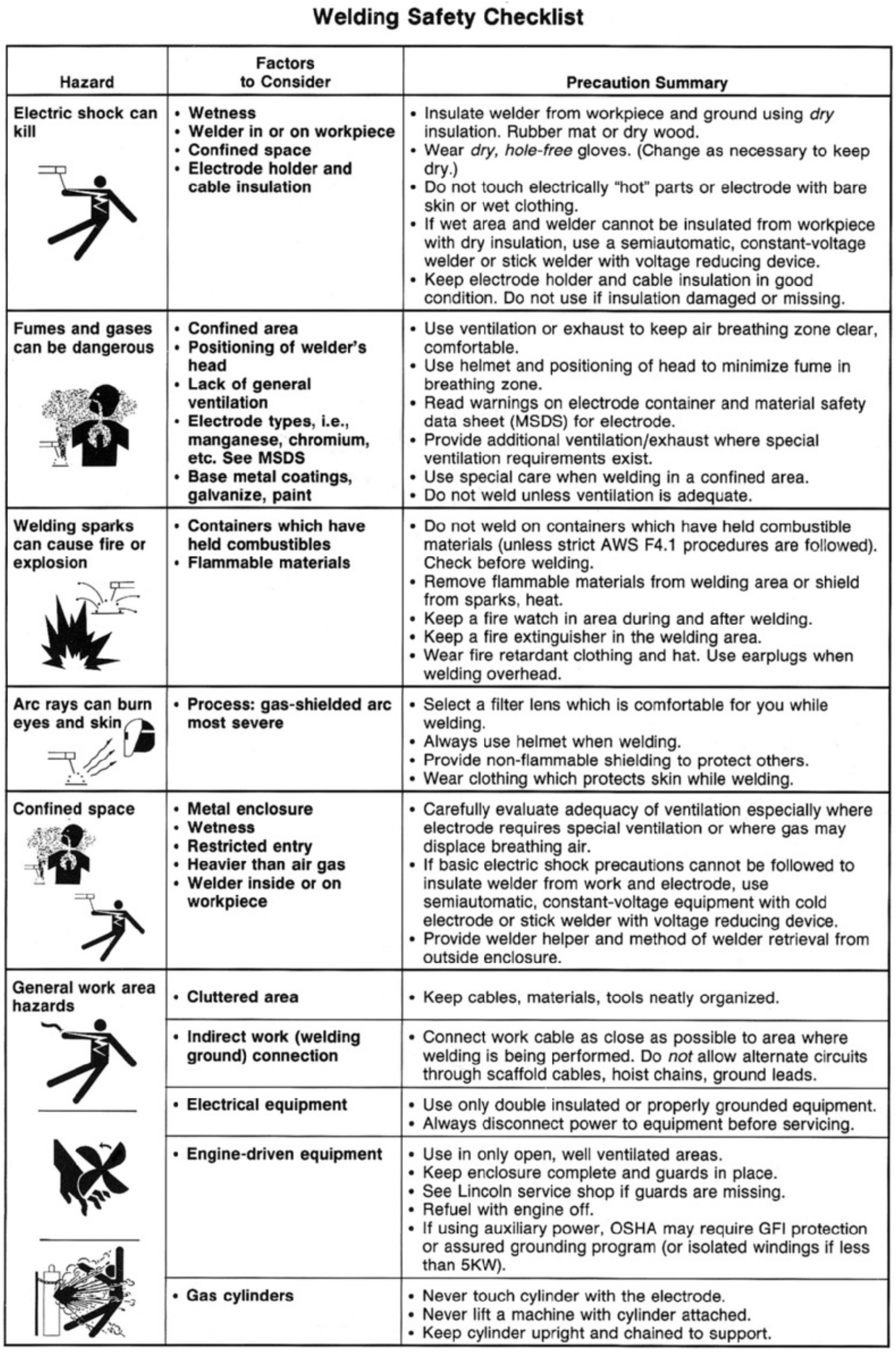
The following safety precautions generally apply to all hammers:

- Check to see that the handle is tight before using any hammer. Never use a hammer with a loose or damaged handle.
- Always use a hammer of suitable size and weight for the job.
- Discard or repair any tool if the face shows excessive wear, dents, chips, mushrooming, or improper redressing.
- Rest the face of the hammer on the work before striking to get the feel or aim; then, grasp the handle firmly with the hand near the end of the handle. Move the fingers out of the way before striking with force.
- A hammer blow should always be struck squarely, with the hammer face parallel to the surface being struck. Always avoid glancing blows and over-and-under strikes.
- For striking another tool (cold chisel, punch, wedge, etc.), the face of the hammer should be proportionately larger than the head of the tool. For example, a 1/2-in. (13-mm) cold chisel requires at least a 1-in. (25-mm) hammer face.
- Never use one hammer to strike another hammer because the face of hammers are very hard and can fracture or chip if struck together.
- Do not use the end of the handle of any tool for tamping or prying; it might split.

ELECTRICAL SAFETY

Electric shock can cause injuries and even death unless proper precautions are taken. Most welding and cutting operations involve electrical equipment in addition to the arc welding power supplies. Grinders, electric motors on automatic cutting machines, and drills are examples. Most electrical equipment in a welding shop is powered by alternating-current (AC) sources and have input voltages ranging from 115 volts to 460 volts. However, fatalities have occurred when working with equipment operating at less than 80 volts. Most electric shocks in the welding industry are a result of accidental contact with bare or poorly insulated conductors. **Electrical resistance** is lowered in the presence of water or moisture, so welders must take special precautions when working under damp or wet conditions, including perspiration. **Figure 2-44** shows a typical **warning label** shipped with the welding equipment.

The workpiece being welded and the frame or chassis of all electrically powered machines must be connected to a good **electrical ground**. The work lead from the welding



Welding Safety Checklist

Hazard	Factors to Consider	Precaution Summary
Electric shock can kill	• Wetness • Welder in or on workpiece • Confined space • Electrode holder and cable insulation	• Insulate welder from workpiece and ground using *dry* insulation. Rubber mat or dry wood. • Wear *dry, hole-free* gloves. (Change as necessary to keep dry.) • Do not touch electrically "hot" parts or electrode with bare skin or wet clothing. • If wet area and welder cannot be insulated from workpiece with dry insulation, use a semiautomatic, constant-voltage welder or stick welder with voltage reducing device. • Keep electrode holder and cable insulation in good condition. Do not use if insulation damaged or missing.
Fumes and gases can be dangerous	• Confined area • Positioning of welder's head • Lack of general ventilation • Electrode types, i.e., manganese, chromium, etc. See MSDS • Base metal coatings, galvanize, paint	• Use ventilation or exhaust to keep air breathing zone clear, comfortable. • Use helmet and positioning of head to minimize fume in breathing zone. • Read warnings on electrode container and material safety data sheet (MSDS) for electrode. • Provide additional ventilation/exhaust where special ventilation requirements exist. • Use special care when welding in a confined area. • Do not weld unless ventilation is adequate.
Welding sparks can cause fire or explosion	• Containers which have held combustibles • Flammable materials	• Do not weld on containers which have held combustible materials (unless strict AWS F4.1 procedures are followed). Check before welding. • Remove flammable materials from welding area or shield from sparks, heat. • Keep a fire watch in area during and after welding. • Keep a fire extinguisher in the welding area. • Wear fire retardant clothing and hat. Use earplugs when welding overhead.
Arc rays can burn eyes and skin	• Process: gas-shielded arc most severe	• Select a filter lens which is comfortable for you while welding. • Always use helmet when welding. • Provide non-flammable shielding to protect others. • Wear clothing which protects skin while welding.
Confined space	• Metal enclosure • Wetness • Restricted entry • Heavier than air gas • Welder inside or on workpiece	• Carefully evaluate adequacy of ventilation especially where electrode requires special ventilation or where gas may displace breathing air. • If basic electric shock precautions cannot be followed to insulate welder from work and electrode, use semiautomatic, constant-voltage equipment with cold electrode or stick welder with voltage reducing device. • Provide welder helper and method of welder retrieval from outside enclosure.
General work area hazards	• Cluttered area	• Keep cables, materials, tools neatly organized.
	• Indirect work (welding ground) connection	• Connect work cable as close as possible to area where welding is being performed. Do *not* allow alternate circuits through scaffold cables, hoist chains, ground leads.
	• Electrical equipment	• Use only double insulated or properly grounded equipment. • Always disconnect power to equipment before servicing.
	• Engine-driven equipment	• Use in only open, well ventilated areas. • Keep enclosure complete and guards in place. • See Lincoln service shop if guards are missing. • Refuel with engine off. • If using auxiliary power, OSHA may require GFI protection or assured grounding program (or isolated windings if less than 5KW).
	• Gas cylinders	• Never touch cylinder with the electrode. • Never lift a machine with cylinder attached. • Keep cylinder upright and chained to support.

Lincoln Electric Company

FIGURE 2-44 Note the warning information contained on this typical label, which may be attached to welding equipment or in the equipment owner's manual.

power supply is not an electrical ground and is not sufficient. A separate lead is required to ground the workpiece and power source.

Electrical connections must be tight. Terminals for welding leads and power cables must be shielded from accidental contact by personnel or by metal objects. Cables must be used within their current-carrying and duty cycle capacities; otherwise, they will overheat and break down the insulation rapidly. Cable connectors for lengthening leads must be insulated.

CAUTION

Welding cables must never be spliced within 10 ft (3 m) of the electrode holder.

Cables must be checked periodically to be sure that they have not become frayed; if they have become frayed, then they must be replaced immediately.

Welders should not allow the metal parts of electrodes or electrode holders to touch their skin or wet coverings on their bodies. Dry gloves in good condition must always be worn. Rubber-soled shoes are advisable. Precautions against accidental contact with bare conducting surfaces must be taken when the welder is required to work in cramped kneeling, sitting, or lying positions. Insulated mats or dry wooden boards are desirable protection from being grounded.

Welding circuits must be turned off when the workstation is left unattended. When working on the welder, welding leads, electrode holder, torches, wire feeder, guns, or other parts of the main power supply must be turned off and locked and tagged to prevent electrocution. Because the electrode holder is energized when changing coated electrodes, the welder must wear dry gloves.

Electrical Safety Systems

For protection from electrical shock, the standard portable power tool is built with either of two equally safe systems: external grounding or double insulation.

A tool with external grounding has a wire that runs from the housing through the power cord to a third prong on the power plug. When this third prong is connected to a grounded, three-hole electrical outlet, the grounding wire will carry any current that leaks past the electrical insulation of the tool away from the user and into the ground. In most electrical systems, the three-prong plug fits into a three-prong, grounded receptacle. If the tool is operated at less than 150 volts, then it has a plug like that shown in **Figure 2-45A**. If it is used at 150 to 250 volts, then it has a plug like that shown in **Figure 2-45B**. In either type, the green (or green and yellow) conductor in the tool cord is the grounding wire. Never connect the grounding wire to a power terminal.

A double-insulated tool has an extra layer of electrical insulation that eliminates the need for a three-pronged plug and grounded outlet. Double-insulated tools do not require grounding and, therefore, have a two-prong plug. In addition, double-insulated tools are always labeled as such on their nameplate or case, **Figure 2-46**.

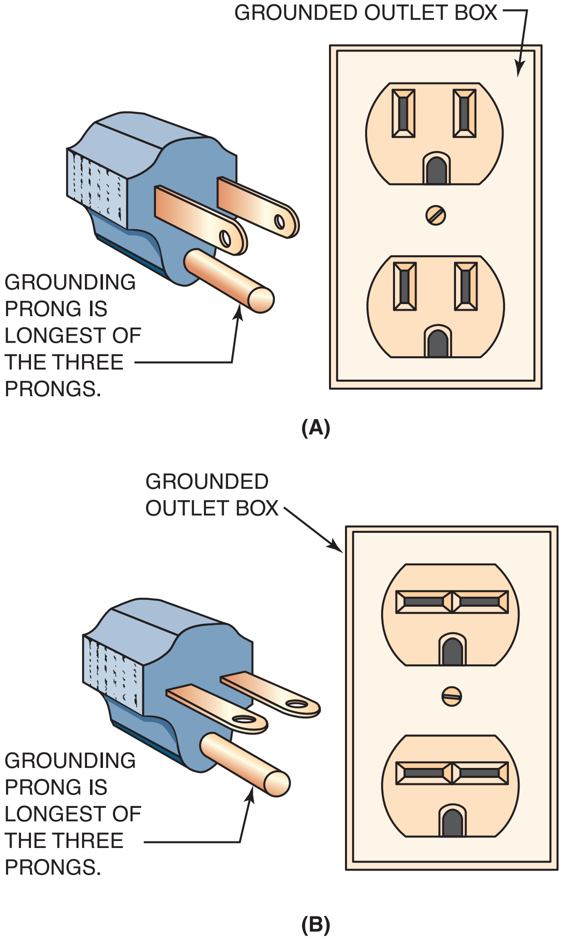


FIGURE 2-45 (A) A three-prong grounding plug for use with up to 150-volt tools and (B) a grounding plug for use with 150- to 250-volt tools.

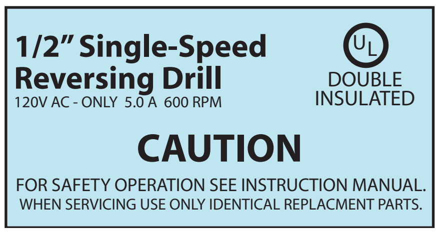


FIGURE 2-46 Typical portable power tool nameplate.

Voltage Warnings

Before connecting a tool to a power supply, be sure the voltage supplied is the same as that specified on the nameplate of the tool. A power source with a voltage greater than that specified for the tool can lead to serious injury to the user as well as damage to the tool. Using a power source with a voltage lower than the rating on the nameplate is harmful to the motor.

Tool nameplates also bear a figure with the abbreviation *amps* (for amperes, a measure of electric current). This refers to the current-drawing requirement of the tool. The higher the input current, the more powerful the motor.

Extension Cords

If there is some distance from the power source to the work area or if the portable tool is equipped with a stub power cord, then an extension cord must be used. When using extension cords on portable power tools, the size of the conductors must be large enough to prevent an excessive drop in voltage. A voltage drop is the lowering of the voltage at the power tool from that of the voltage at the supply. This occurs because of resistance to electrical flow in the wire. A voltage drop causes loss of power, overheating, and possible motor damage. **Table 2-2** shows the correct size extension cord to use based on cord length and nameplate amperage rating. If in doubt, use the next larger size. The smaller the gauge number of an extension cord, the larger the cord.

Only three-wire, grounded extension cords connected to properly grounded, three-wire receptacles should be used. Two-wire extension cords with two-prong plugs should not be used. Current specifications require outdoor receptacles to be protected with **ground-fault circuit interrupter (GFCI)** devices. These safety devices are often referred to as a GFI.

When using extension cords, keep in mind the following safety tips:

- Always connect the cord of a portable electric power tool into the extension cord before the extension cord is connected to the outlet.
- Always unplug the extension cord from the receptacle before unplugging the cord of the portable power tool from the extension cord.
- Extension cords should be long enough to make connections without being pulled taut, creating unnecessary strain or wear, but should not be excessively long.
- Be sure that the extension cord does not come in contact with sharp objects or hot surfaces. The cords should not be allowed to kink, nor should they be dipped in or splattered with oil, grease, or chemicals.
- Before using a cord, inspect it for loose or exposed wires and damaged insulation. If a cord is damaged, then replace it. This also applies to the tool's power cord.
- Extension cords should be checked frequently while in use to detect unusual heating. Any cable that feels more than slightly warm to a bare hand placed outside the insulation should be checked immediately for overloading.
- See that the extension cord is positioned so that no one trips or stumbles over it.
- To prevent the accidental separation of a tool cord from an extension cord during operation, make a knot as shown in **Figure 2-47A** or use a cord connector as shown in **Figure 2-47B**.
- Extension cords that go through dirt and mud must be cleaned before storing.

Nameplate Amperes	Cord Length in Feet							
	25	50	75	100	125	150	175	20
1	16	16	16	16	16	16	16	16
2	16	16	16	16	16	16	16	16
3	16	16	16	16	16	16	14	14
4	16	16	16	16	16	14	14	12
5	16	16	16	16	14	14	12	12
6	16	16	16	14	14	12	12	12
7	16	16	14	14	12	12	12	10
8	14	14	14	14	12	12	10	10
9	14	14	14	12	12	10	10	10
10	14	14	14	12	12	10	10	10
11	12	12	12	12	10	10	10	8
12	12	12	12	12	10	10	8	8

TABLE 2-2 Recommended Extension Cord Sizes for Use with Portable Electric Tools

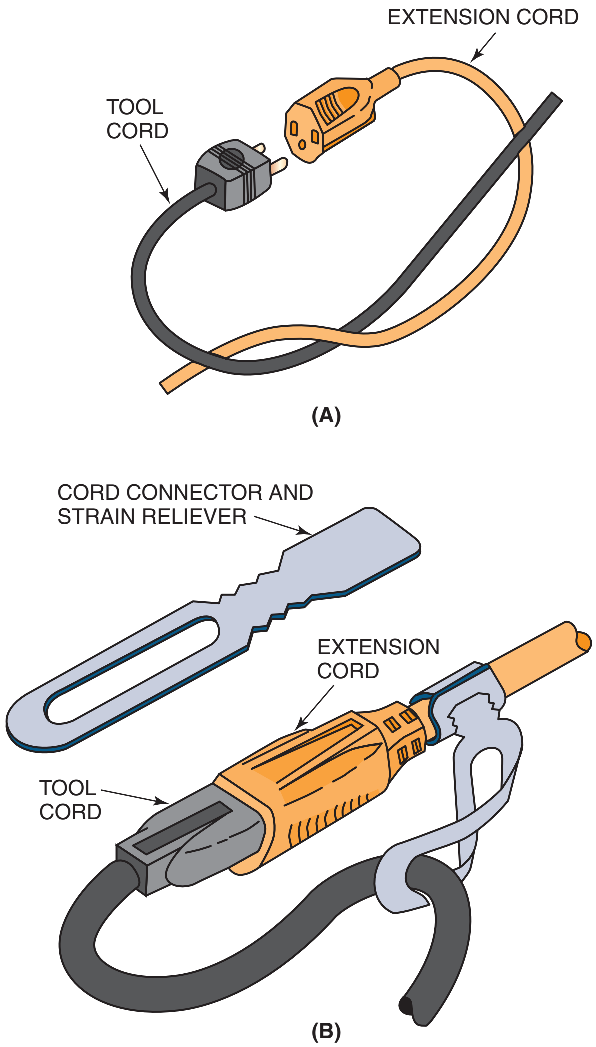


FIGURE 2-47 (A) A knot will prevent the extension cord from accidentally pulling apart from the tool cord during operation. (B) A cord connector will serve the same purpose.

Safety Rules for Portable Electric Tools

In all tool operations, safety is simply the removal of any element of chance. The following are a few safety precautions that should be observed. These are general rules that apply to all power tools. They should be strictly obeyed to avoid injury to the operator and damage to the power tool.

- Know the tool. Learn the tool's applications and limitations as well as its specific potential hazards by reading the manufacturer's literature.
- Ground the portable power tool unless it is double-insulated. If the tool is equipped with a three-prong plug, then it must be plugged into a three-hole electrical receptacle. Never remove the third prong.
- Do not expose the power tool to water or rain. Do not use a power tool in wet locations.
- Keep the work area well-lighted. Avoid chemical or corrosive environments.
- Because electric tools spark, portable electric tools should never be started or operated in the presence of propane, natural gas, gasoline, paint thinner, acetylene, or other flammable vapors that could cause a fire or explosion.
- Do not force a cutting tool to cut faster. It will do the job better and more safely if operated at the cutting rate for which it was designed.
- Use the right tool for the job. Never use a tool for any purpose other than that for which it was designed.
- Wear eye protectors. Safety glasses or goggles will protect the eyes while you operate power tools.
- Wear a face or dust mask if the operation creates dust.
- Take care of the power cord. Never carry a tool by its cord or yank it to disconnect it from the receptacle.
- Secure your work with clamps. It is safer than using your hands, and it frees both hands to operate the tool.
- Do not overreach when operating a power tool. Keep proper footing and balance at all times.
- Maintain power tools. Follow the manufacturer's instructions for lubricating and changing accessories. Replace all worn, broken, or lost parts immediately.
- Disconnect the tools from the power source when they are not in use.
- Form the habit of checking to see that any keys or wrenches are removed from the tool before turning it on.
- Avoid accidental starting. Do not carry a plugged-in tool with your finger on the switch. Be sure the switch is off when plugging in the tool.
- Be sure accessories and cutting bits are attached securely to the tool.
- Do not use tools with cracked or damaged housings.
- When operating a portable power tool, give it your full and undivided attention; avoid dangerous distractions.
- Never use a power tool if its safeties or guards have been removed or are inoperable.

POWER TOOLS

Welders use a wide variety of power tools to help them produce welded products. Read the tool manufacturer's safety, operating, and maintenance manuals and get instructions from your instructor or welding shop foremen before operating any power tool for the first time. If the equipment manuals are not available, then you can check the web or local distributor for replacement documentation.

Grinders

Grinding using a pedestal grinder or a portable grinder is required to do many welding jobs correctly. Often it is necessary to grind a groove, remove rust, or smooth a weld. Grinding stones have the maximum revolutions per minute (RPM) listed on the paper blotter, **Figure 2-48**. They must never be used on a machine with a higher-rated RPM. If grinding stones are turned too fast, they can explode.

Grinding Stone Before a grinding stone is put on the machine, it should be tested for cracks. This is done by tapping the stone in four places and listening for a sharp ring, which indicates it is good, **Figure 2-49**. A dull sound indicates that the grinding stone is cracked and should not be used. Once a stone has been installed and has been used, it may need to be trued and balanced by using a special tool designed for that purpose, **Figure 2-50**. Truing keeps the stone face flat and sharp for better results.

Larry Jeffus

FIGURE 2-48 Always check to be sure that the grinding stone and the grinder are compatible before installing the stone.

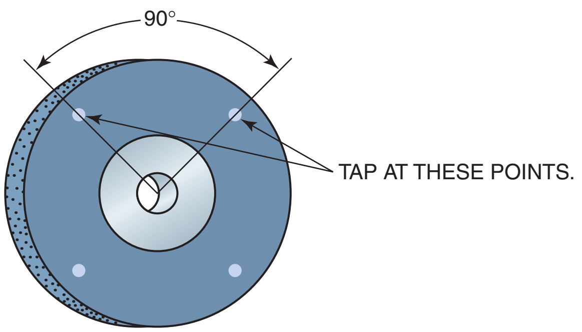


FIGURE 2-49 Grinding stones should be checked for cracks before they are installed.

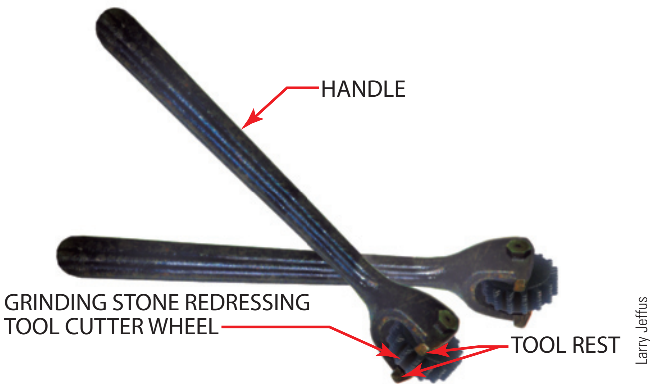


FIGURE 2-50 Use a grinding stone redressing tool as needed to keep the stone in balance.

Types of Grinding Stones Each grinding stone is made for grinding specific types of metal. Most stones are for ferrous metals, meaning iron, cast iron, steel, and stainless steel, among others. Some stones are made for nonferrous metals such as aluminum, copper, and brass. If a ferrous stone is used to grind nonferrous metal, then the stone will become glazed (the surface clogs with metal) and may explode due to frictional heat building up on the surface. If a nonferrous stone is used to grind ferrous metal, then the stone will be quickly worn away.

When the stone wears down, keep the tool rest adjusted to within 1/16 in. (2 mm), **Figure 2-51**, so that the metal being ground cannot be pulled between the tool rest and the stone surface. Stones should not be used when they are worn down to the size of the paper blotter. If small parts become hot from grinding, pliers can be used to hold them. Gloves should never be worn when grinding. If a glove gets caught in a stone, the whole hand may be drawn in.

The sparks from grinding should be directed down and away from other people or equipment.

Drills

Before starting to drill, secure the workpiece as necessary and fasten it in a vise or clamp. Holding a small item in your hand can cause injury if it is suddenly seized by the bit and whirled from your grip. This is most likely to happen just as the bit breaks through the hole at the back side of the work. All sheet metal tends to cause the bit to grab as it goes through. This can be controlled by reducing the pressure on the drill just as the bit starts to go through the workpiece.

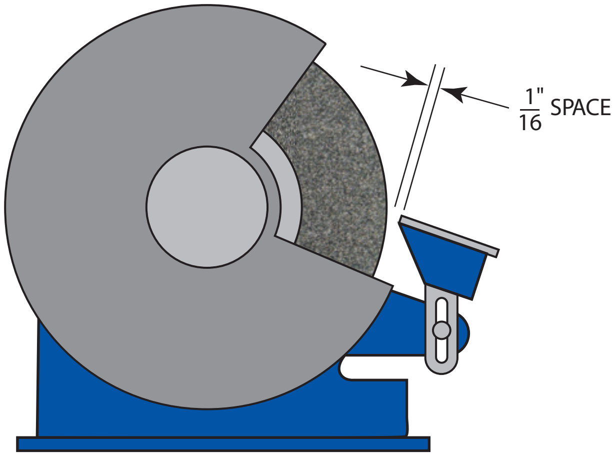


FIGURE 2-51 Keep the tool rest adjusted.

Carefully center the drill bit in the jaws of the chunk and securely tighten it. Do not insert the bit off center, because it will wobble and probably break when it is used. Drill bits that are 1/4 in. (6 mm) may be hand-tightened in the drill chuck to prevent them from snapping if they are accidentally grabbed. Hand-tightening the small bits allows them to spin in the chuck if necessary, thus reducing bit breakage. This technique does not always work because some chunks cannot hold the bits securely enough to prevent them from spinning during normal use. In these cases, the chunk must be tightened securely with a chuck key.

When possible, center-punch the workpiece before drilling to prevent the drill bit from moving across the surface as the drilling begins. After centering the drill bit tip on the exact point at which the hole is to be drilled, start the motor by pulling the trigger switch. Never apply a spinning drill bit to the work. With a variable-speed drill, run it at a very low speed until the cut has begun. Then, gradually increase to the optimum drill speed.

Except when it is desirable to drill a hole at an angle, hold the drill perpendicular to the face of the work. Align the drill bit and the axis of the drill in the direction the hole is to go and apply pressure only along this line, with no sideways or bending pressure. Changing the direction of pressure will distort the dimensions of the hole and might snap a small drill bit.

Use just enough steady, even pressure to keep the drill cutting. Guide the drill by leading it slightly, if needed, but do not force it. Too much pressure can cause the bit to break or overheat. Too little pressure will keep the bit from cutting and dull its edges due to the friction created by sliding over the surface.

If the drill becomes jammed in the hole, release the trigger immediately, remove the drill bit from the work, and determine the cause of the stalling or jamming. Do not squeeze the trigger on or off in an attempt to free a stalled or jammed drill. When using a reversing-type model, the direction of the rotation may be reversed to help free a jammed bit. Be sure the direction of the rotation is reset before trying to continue drilling.

Reduce the pressure on the drill just before the bit cuts through the work to avoid stalling in metal. When the bit has completely penetrated the work and is spinning freely, withdraw it from the work while the motor is still running, and then turn off the drill.

Metal Cutting Machines

Many types of mechanical metal cutting machines are used in the welding shop—for example, shears, punches, cut-off machines, and band saws. Their advantages over thermal cutting include little or no postcutting cleanup, the wide variety of metals that can be cut, and the fact that the metal is not heated.

CAUTION

Before operating any power equipment for the first time, you must read the manufacturer's safety and operating instructions and should be assisted by someone with experience with the equipment. Be sure your hands are clear of the machine before the equipment is started. Always turn off the power and lock it off before working on any part of the equipment.

Shears and Punches Welders frequently use shears and punches in the fabrication of metal for welding. These machines can be operated either by hand or by powerful motors. Hand-operated equipment is usually limited to thin sheet stock or small bar stock. Powered equipment can be used on material an inch or more in thickness and several feet wide, depending on its rating. Their power can be a potential danger if these machines are not used correctly. Both shears and punches are rated by the thickness, width, and type of metal with which they can be safely used. Failure to follow these limitations can result in damage to the equipment, damage to the metal being worked, and injury to the operator.

Shears work like powerful scissors. The correct placement of the metal being cut is as close to the pivot pin as possible, **Figure 2-52**. The metal being sheared must be securely held in place by the clamp on the shear before it is cut. If you are cutting a long piece of metal that is not being supported by the shear table, then portable supports must be used. As the metal is being cut, it may suddenly move or bounce around; if you are holding onto it, this can cause a serious injury.

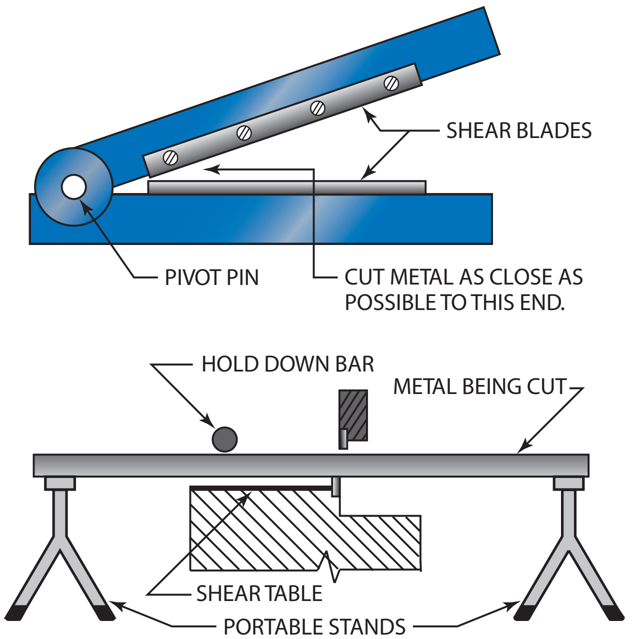


FIGURE 2-52 Power shear.

Power punches are usually either hydraulic or flywheel-operated. Both types move quickly, but only the hydraulic can usually be stopped mid-stroke. Once the flywheel-type punch has been engaged, in contrast, it will make a complete cycle before it stops. Because punches move quickly or may not be stopped, it is very important that the operator's two hands be clear of the machine and that the metal be held firmly in place by the machine clamps before starting the punching operation.

Cut-Off Machines Cut-off machines may use abrasive wheels or special saw blades to make their cuts. Most abrasive cut-off wheels spin at high speeds (high RPMs) and are used dry (without coolant). Most saws operate much more slowly and with a liquid coolant. Both types of machines produce quality cuts in a variety of bar-shaped or structural-shaped metals. The cuts require little or no postcut cleanup. Always wear eye protection when operating these machines. Before a cut is started, the metal must be clamped securely in the machine vise. Even the slightest movement of the metal can bind or break the wheel or blade. If the machine has a manual feed, then the cutting force must be applied at a smooth and steady rate. Apply only enough force to make the cut without dogging down the motor. Use only reinforced abrasive cut-off wheels that have an RPM rating equal to or higher than the machine-rated speed.

Band Saws Band saws can be purchased as vertical or horizontal, and some can be used in either position. Some band saws can be operated with a cooling liquid and are called *wet saws*; most small saws operate dry. The blade guides must be adjusted as closely as possible to the metal being cut. The cutting speed and cutting pressure must be low enough to prevent the blade from overheating. When

using a vertical band saw with a manual feed, you must keep your hands away from the front of the blade so that if your hand slips, it will not strike the moving blade. If the blade breaks, sticks, or comes off the track, turn off the power, lock it off, and wait for the band saw drive wheels to come to a complete stop before touching the blade. Be careful of hot flying chips.

MATERIAL HANDLING

Proper lifting, moving, and handling of large, heavy welded assemblies are important to the safety of the workers and the weldment. Improper work habits can cause serious personal injury as well as cause damage to equipment and materials.

Lifting

When you are lifting a heavy object, the weight of the object should be distributed evenly between both hands, and you should use your legs, not your back, to lift, **Figure 2-53**. Do not try to lift a large or bulky object without help if the object is heavier than you can lift with one hand.

Hoists or Cranes

The capacity of hoists or cranes should be checked before trying to lift a load. They can be accidentally overloaded

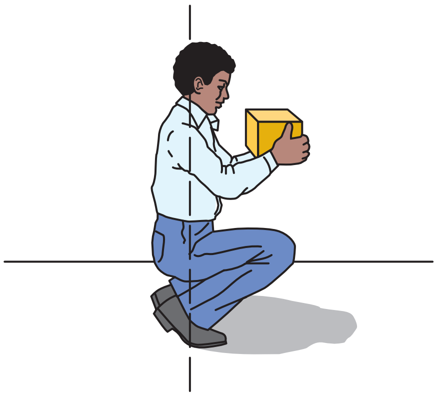


FIGURE 2-53 Lift with your legs, not your back.

with welded assemblies. Keep any load as close to the ground as possible while it is being moved. Pushing a load on a crane is better than pulling a load. It is advisable to stand to one side of ropes, chains, and cables that are being used to move or lift a load, **Figure 2-54**. If they break and snap back, they will miss you. If it is necessary to pull a load, use a rope, **Figure 2-55**.

LADDER SAFETY

Improper use of ladders is often a factor in falls. Always keep this in mind when erecting a ladder; even short step stools can pose a potential fall hazard. Never approach a climb assuming that because it is not high, it cannot be that dangerous. All ladder usage poses a danger to your safety. Some welders think that if a ladder starts to fall they will just "jump clear." You cannot jump clear if the ladder under you has given way because there is nothing solid under your feet for you to jump from. When a ladder falls, you fall. Keep the area around the base of the ladder clear so if you do fall, it will not be into debris or equipment.

Types of Ladders

Both stepladders and straight ladders are used extensively in welding fabrication. Straight ladders may be single section or extension-type ladders. Most ladders are made from wood, aluminum, or fiberglass, each type of which has its advantages and disadvantages, **Table 2-3**. All ladders used in welding should be listed with the American National Standards Institute (ANSI) and Underwriters Laboratories (UL) to ensure that they are constructed to a standard of safety.

Ladder Inspection

Over time, ladders can become worn or damaged and should be inspected each time they are used. Look for loose or damaged steps, rungs, rails, braces, and safety feet. Check to see that all hardware is tight, including hinges, locks, nuts, bolts, screws, and rivets. Wooden

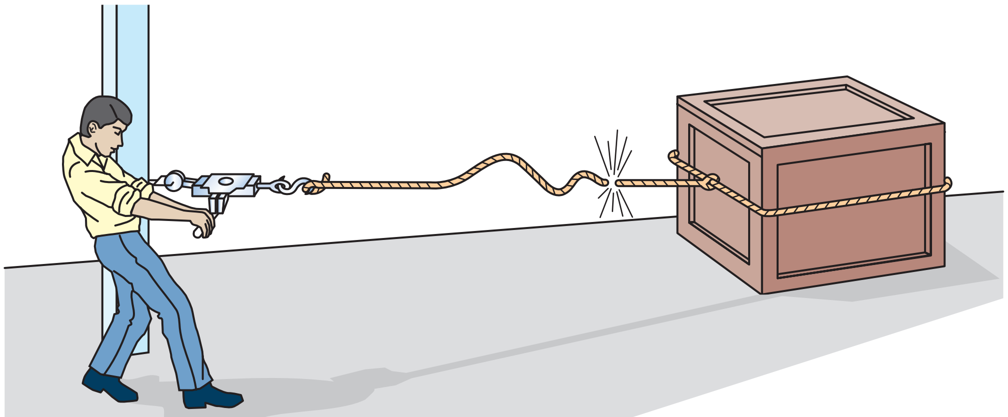


FIGURE 2-54 Never stand in line with a rope, chain, or cable that is being used to move or lift a load.

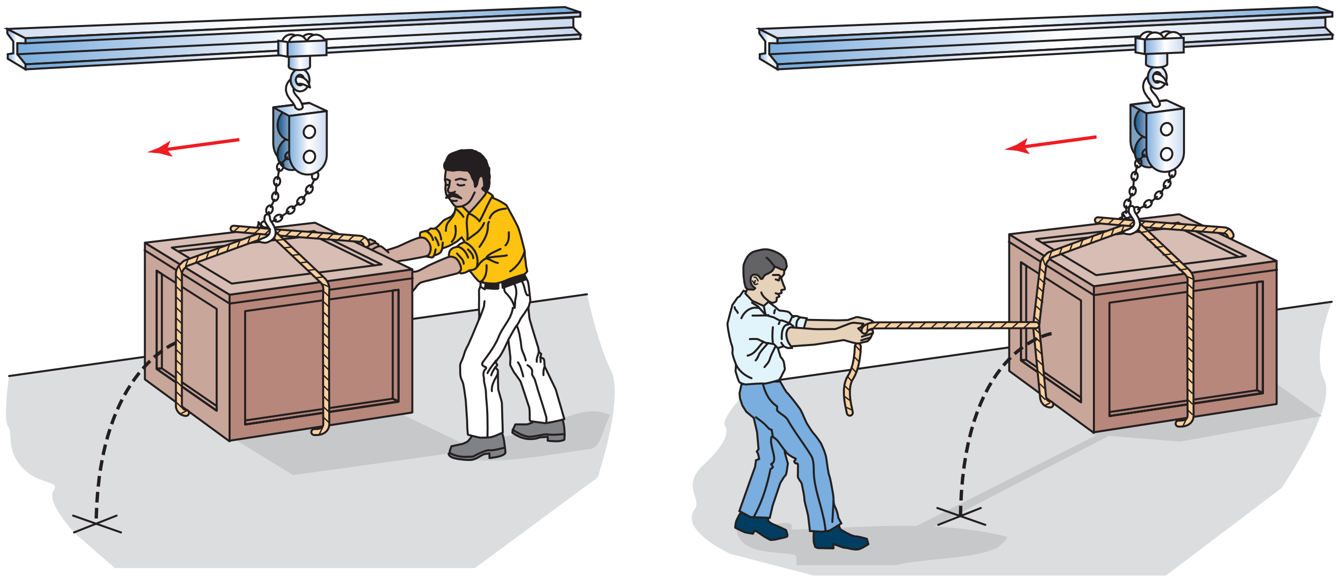


FIGURE 2-55 When moving a load overhead, stay out of the way of the load in case it falls.

Material	Advantages	Disadvantages
Wood	Electrically non-conductive	Long-term exposure to weather will cause rotting
Aluminum	Light weight Weather resistant	Electrically conductive Shakier than wood or fiberglass
Fiberglass	Electrically non-conductive Weather resistant	Heavier than aluminum and wood Fiberglass splinters

TABLE 2-3 Common Materials Used for Ladders and Their Advantages and Disadvantages

ladders must be checked for cracks, rot, or wood decay. Never use a defective ladder. Make any necessary repairs before it is used or, if it cannot be repaired, replace it.

Rules for Ladder Use

Read the entire ladder manufacturer's list of safety rules before using the ladder for the first time. Stepladders must be locked in the full opened position with the spreaders. Straight or extension ladders must be used at the proper angle; an angle that is either too steep or too flat is dangerous, **Figure 2-56**.

The following are general safety and usage rules for ladders:

- Follow all recommended practices for safe use and storage.
- Do not exceed the manufacturer's recommended maximum weight limit for the ladder.
- Before setting up a ladder, make certain it will be erected on a level, solid surface.
- Never use a ladder in a wet or muddy area where water or mud will be tracked up the ladder's steps or rungs. Only climb or descend ladders with clean, dry shoes.
- Tie the ladder securely in place.

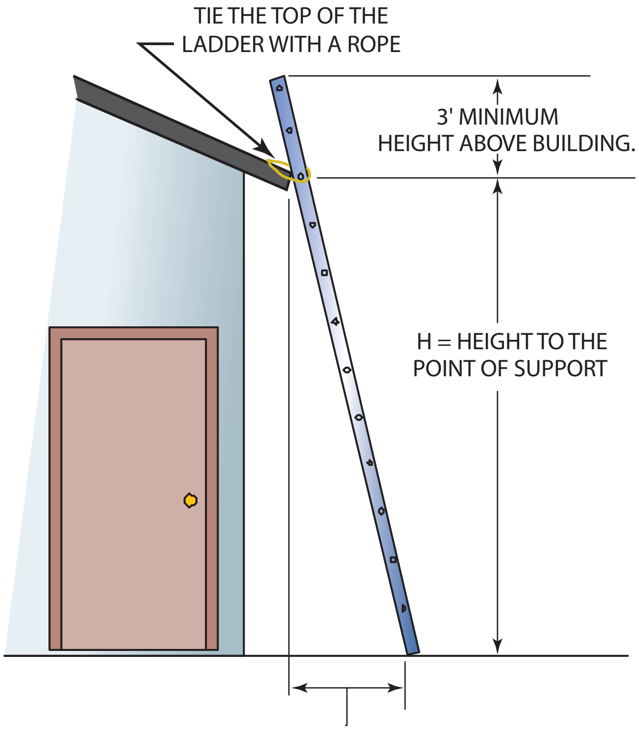


FIGURE 2-56 Make sure the ladder is leaning at the proper angle.

- Climb and descend the ladder cautiously.
- Do not carry tools and supplies in your hand as you climb or descend a ladder. Use a rope to raise or lower the items once you are safely in place.
- Never use ladders around live electrical wires.
- Never use a ladder that is too short for the job so you have to reach or stand on the top step.
- Wear well-fitted shoes or boots.

Summary

The safety of the welder working in industry is of utmost importance to the industry. A sizable amount of money is spent on the protection of welders. Usually, manufacturers have a safety department with one individual in charge of plant safety. The safety officer's job is to make sure that all welders comply with safety rules during production. The proper clothing, shoes, and eye protection to be worn are emphasized in these plants. Any worker who does not follow established safety rules is subject to dismissal.

If an accident does occur, then it is important that appropriate and immediate first aid steps are taken. All welding shops should have established plans for actions to take in case of accidents. You should take time to learn the proper procedure for accident response and reporting before you need to respond in an emergency. After the situation has been properly taken care of, you should complete an accident report.

Equipment is periodically checked to be sure that it is safe and in proper working condition. Maintenance workers are employed to see that the equipment is in proper working condition at all times.

Further safety information is available in *Safety for Welders*, by Larry F. Jeffus, published by Delmar/Cengage Learning, and from the American Welding Society or the U.S. Department of Labor (OSHA) regulations.

Review

1. What is the key to preventing accidents in a welding shop?
2. Who is ultimately responsible for the welder's safety?
3. Describe the three classifications of burns.
4. What emergency steps should be taken to treat burns?
5. List the three types of light that may be present during welding.
6. Which type of light is the most likely to cause burns? Why?
7. What can be done on the job site to reduce the danger of reflected light?
8. What is the name of the eye burn that can occur in a fraction of a second?
9. In what two ways can ultraviolet light burn the eyes?
10. Why is it important to seek medical treatment for eye burns?
11. What fabric(s) are the best choice to wear as general work clothing in a welding shop?
12. Describe the ideal work shirt, pants, boots, and caps that should be worn in a welding shop.
13. Why is it unsafe to carry butane lighters or matches in your pockets while welding?
14. What special protective items can be worn to provide extra protection for a welder's hands, arms, body, waist, legs, and feet?
15. Why must eye protection be worn at all times in the welding shop?
16. What types of injuries can occur to the ears during welding?
17. What types of protection are available to protect the ears during welding?
18. What types of information should be covered in a respirator training program?
19. Name two types of respirators and describe how they work.
20. List the materials that can give off dangerous fumes during welding and require forced ventilation.
21. Why must metal that has been used before be cleaned prior to welding?
22. Under what conditions can natural ventilation be used?
23. Name two advantages of recycling scrap metal.
24. When must forced ventilation be used?
25. Who must be provided with safety data sheets (SDSs)?
26. Describe an acceptable storage area for a cylinder of fuel gas.

27. How must high-pressure gas cylinders be stored so they cannot be accidentally knocked over?

28. What should be done with a leaking cylinder if the leak cannot be stopped?

29. Why is it important for acetylene cylinders to not be stored horizontally?

30. What is hot work?

31. How far away should highly combustible materials be from any welding or cutting?

32. When is a fire watch needed?

33. List the four types of fire extinguishers and the types of material for which they are used.

34. Why is it important to have a planned maintenance program for tools and equipment?

35. Why is it important to keep a welding area clean?

36. What should you do if you have to leave a piece of hot metal unattended?

37. Why must a mushroomed chisel or hammer be reground?

38. What causes most electric shock in the welding industry?

39. According to the Welding Safety Checklist in Figure 2-44, what are the factors necessary for a confined space hazard?

40. What can happen if too much power is being carried by a cable?

41. Why must equipment be turned off and unplugged before working on the electrical terminals?

42. According to Table 2-2, what gauge wire size would be needed for a power tool that has a nameplate amperage of 9 and a cord length of 100 ft?

43. What is a GFCI?

44. List five safety tips for safe extension cord use.

45. List 10 safety rules for the safe use of portable electric tools.

46. Why is it important to not weld when everything is wet?

47. List two types of grinders used by welders.

48. How close to the grinding stone face should the tool rest be adjusted?

49. Name metal cutting machines used in the welding shop and their advantages.

50. Describe how a person should safely lift a heavy object.

51. List the things that should be inspected on a ladder.

52. List and explain five ladder use safety rules.

Section 2

Shielded Metal Arc Welding

Success Story

My name is Matthew Lee, and I remember the first time I struck an arc. In that moment, I knew that was something I could do and make a career out of. Before welding, I had no idea what I was going to do with my life after high school. Working in a fast food restaurant, I knew that was no way to make a living. So welding created a new opportunity and direction for my life. With the support and encouragement of my instructors Mr. Black and Mr. Grattan at Lexington Technology Center in Lexington, South Carolina, I tried to learn the most I could about welding. In the shop I strived to get better and better with each weld I made. Life was stressful and a wreck at that time, but welding gave me a way to relax and focus on something other than what was going on in my life. While in my senior year of high school and third year of welding, I was given the opportunity to attend the Skills USA competition. I didn't win, but it was an amazing opportunity and helped sharpen my skills.

After graduation, I made it a goal to get on at a local steel building manufacturing plant. This was not an easy task, considering I had no previous work history in the manufacturing industry. I had already started the application process once while I was still in high school; it's a four-step process, and I didn't even make it past the first step. I was disappointed, but it didn't get me down. I then found a job working in a local warehouse pulling stock to be loaded on trucks. It wasn't something I liked or even wanted to do; but since I was out of school, I wanted to do something full time and make some more money.

Another opportunity came to apply for a welding job at the manufacturing plant; this time I made it to the second step. To my surprise this step had nothing to do with welding but was all about teamwork, working with others, taking instructions, etc. It consisted of over 100 questions about myself, such as "what if" and "how would you react in a situation." I received a letter about two weeks later stating I didn't make it past the second step. I almost gave up, but my high school instructors continued to give me hope and encouragement.

About four months later, the manufacturing plant was hiring again, and I decided to give it one more try. I made it past the first two steps, and the next two consisted of interviews. All of this took about three months. I was scheduled to come back up to the plant for a meeting with the production manager, and at the meeting I was given the job as a welder. I have been on the job a little over a year now and still enjoy what I do; I plan on making this my career and possibly moving into a management position later on in life.

I wouldn't be in the position I'm in today if it weren't for the support and encouragement of my high school welding instructors, Mr. Black and Mr. Grattan; my family; friends; and church family. I have continued to stay in contact with the LTC welding program and try to go there and speak with the students when I have a chance. It's always nice to go back to the place I started at and see all the new talent.

Chapter 3

Shielded Metal Arc Equipment, Setup, and Operation

OBJECTIVES

After completing this chapter, the student should be able to

- describe the process of shielded metal arc welding (SMAW).
- list and define the three units used to measure a welding current.
- tell how adding chemicals to the coverings of the electrodes affects the arc.
- discuss the three different types of current used for welding.
- explain the types of welding power supplies and which type the shielded metal arc welding process requires.
- define *open circuit voltage* and *operating voltage*.
- explain arc blow, what causes it, and how to control it.
- tell what the purpose of a welding transformer is and what kind of change occurs to the voltage and amperage with a step-down transformer.
- compare generators and alternators.
- tell the purpose of a rectifier.
- read a welding machine duty cycle chart and explain its significance.
- demonstrate how to determine the proper welding cable size.
- demonstrate how to service and repair electrode holders.
- discuss the problems that can occur as a result of poor work lead clamping.
- describe the factors that should be considered when placing an arc welding machine in a welding area.

KEY TERMS

amperage
anode
cathode
duty cycle
electrons
inverter
magnetic flux lines
open circuit voltage
operating voltage
output
rectifier
step-down transformer
voltage
wattage
welding cables
welding leads

INTRODUCTION

Shielded metal arc welding (SMAW) is a welding process that uses a flux-covered metal electrode to carry an electrical current, **Figure 3-1**. The current forms an arc across the gap between the end of the electrode and the work. The electric arc creates sufficient heat to melt both the electrode and the work. Molten metal from the electrode travels across the arc to the molten pool on the base metal, where they mix together. The end of the electrode and molten pool of metal is surrounded, purified, and protected by a gaseous cloud and a covering of molten flux produced as the flux coating of the electrode burns or vaporizes. As the arc moves away, the mixture of molten electrode and base metal solidifies and becomes one piece. At the same time, the molten flux solidifies, forming a solid slag. Some electrode types produce heavier slag coverings than others.

SMAW is a widely used welding process because of its low cost, flexibility, portability, and versatility. The machine and the electrodes are low in cost. The machine itself can be as simple as a 110-volt, step-down transformer. The electrodes are available from a large number of manufacturers in packages from 1 lb (0.5 kg) to 50 lb (22 kg).

The SMAW process is very versatile because the same SMA welding machine can be used to make a wide variety of weld joint designs in a wide variety of metal types and thicknesses, and in all positions:

- Joint designs—In addition to the standard butt, lap, tee, and outside corner joints, at some time SMAW has been certified to be used to weld every possible joint design.
- Metal types—Although mild steel is the most commonly welded metal, a wide variety of electrode types allow SMA to be used to weld and hardface almost any metal or alloy, including cast iron, aluminum, stainless steel, and nickel.
- Metal thickness—Metal as thin as 16 gauge, approximately 1/16 in. (2 mm) thick up to several feet thick, can be SMA welded.

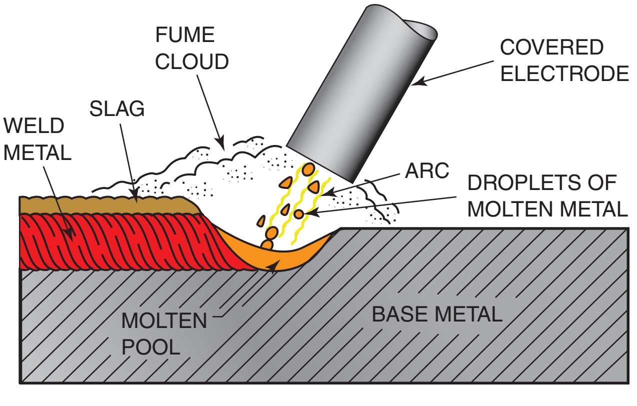


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FIGURE 3-1 Shielded metal arc welding.

- All positions—The flat welding position is the easiest and most productive because large welds can be made fast using SMA welding, but the process can be used to make welds in any position.

SMAW is a very portable process because it is easy to move the equipment, and engine-driven generator-type welders are available. Also, the limited amount of equipment required for the process makes moving easy.

WELDING CURRENT

The source of heat for arc welding is an electric current. An electric current is the flow of **electrons**. Electrons flow through a conductor from negative (−) to positive (+), **Figure 3-2**. Resistance to the flow of electrons (electricity) produces heat. The greater the resistance, the greater the heat. Air has a high resistance to current flow. As the electrons jump the air gap between the end of the electrode and the work, a great deal of heat is produced. Electrons flowing across an air gap produce an arc.

ELECTRICAL MEASUREMENT

Three units are used to describe any electrical current. The three units are voltage (V), amperage (A), and wattage (W).

- **Voltage**, or **volts** (V), is the measurement of electrical pressure in the same way that pounds per square inch is a measurement of water pressure. Voltage controls the maximum gap the electrons can jump to form the arc. A higher voltage can jump a larger gap. Welding voltage is associated with the welding arc's temperature.
- **Amperage**, or **amps** (A), is the measurement of the total number of electrons flowing, in the same way that gallons is a measurement of the amount of water flowing. Amperage controls the size of the arc. Amperage is associated with the welding arc's heat.
- **Wattage**, or **watts** (W), is a measurement of the amount of electrical energy or power in the arc. Watts are calculated by multiplying voltage (V) times amperes (A), **Figure 3-3**. Watts are the welding arc's power or how much energy the arc is producing, **Figure 3-4**.

Temperature and Heat

The term *temperature* refers to the degree or level of thermal energy in a material and can be measured in degrees with a thermometer. The term *heat* refers to the quantity of thermal energy in a material and cannot be easily measured. Temperature and heat are to some degree related to each other, but they can change independently. For example, the small, red-hot spark from a grinder and a red-hot weld

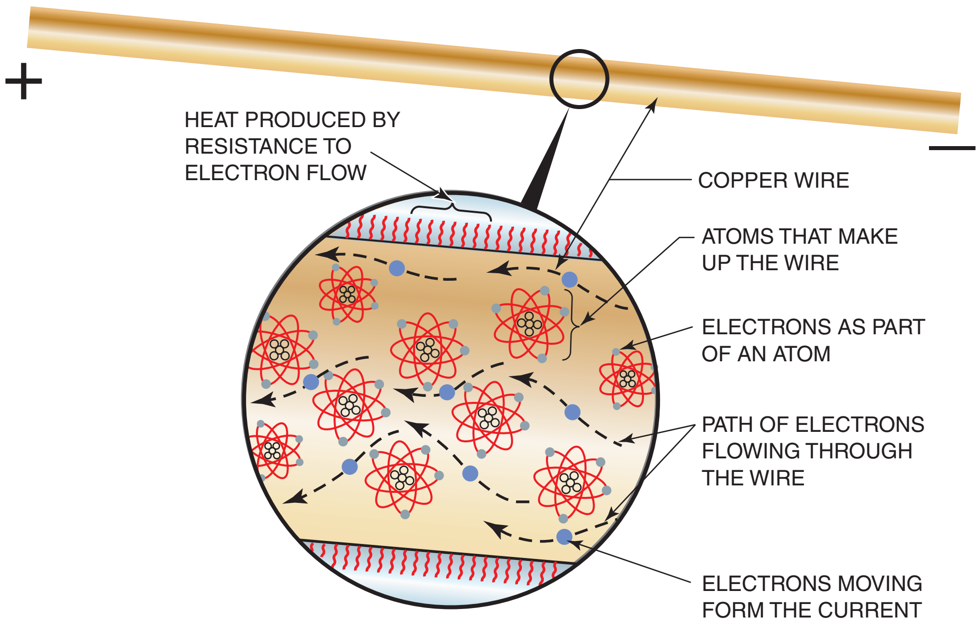


FIGURE 3-2 Electrons traveling along a conductor.

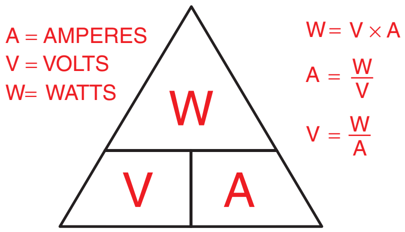


FIGURE 3-3 Ohm's Law.

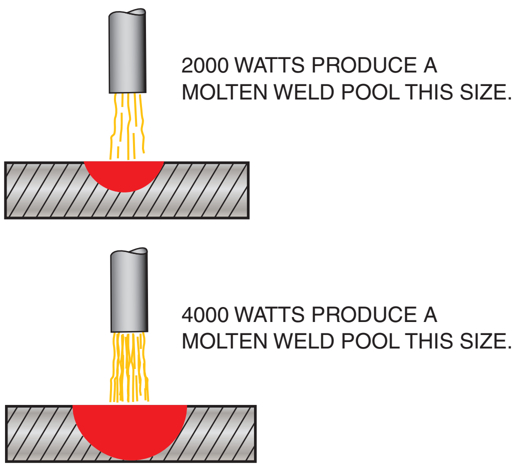


FIGURE 3-4 The molten weld pool size depends on the energy (watts), the metal mass, and thermal conductivity.

are both at the same temperature, but the weld has more heat. So the quantity of heat in a material is a function of both its temperature and its weight (mass). Another example is a match and a bonfire; both are burning at the same temperature, but the burning match does not produce the same quantity of heat as the bonfire. Likewise, the temperature of an arc from both a small diameter electrode and a large diameter electrode is the same, but the larger arc has more heat.

SMA Welding Arc Temperature

An arc's temperature is dependent on the voltage, arc length, and the atmosphere (gas or vapor) it is passing through. The arc temperature can range from approximately 5500°F (3000°C) to more than 36,000°F (20,000°C), but most SMA welding arcs have effective temperatures of approximately 11,000°F (6100°C). The voltage and arc length are closely related because as the arc length increases, the arc resistance increases; therefore, it takes a higher voltage (pressure) to keep the electrons flowing (jumping) across the gap. The shorter the arc, the lower the arc's resistance and the lower the arc's voltage and the lower the temperature produced; as the arc lengthens, the resistance increases, thus causing an increase in the arc voltage and temperature.

Most shielded metal arc welding electrodes have chemicals added to their coverings to stabilize the arc. These arc stabilizers form conductive ions (gas or vapors) that make the arc more stable and reduce the arc resistance. This makes it easier to hold an arc. By lowering the resistance, the arc stabilizers also lower the arc temperature. Changing the chemicals in the electrode flux will cause changes within the gaseous cloud around the arc. These changes may raise or lower the resistance, thus raising or lowering the welds temperature and heat.

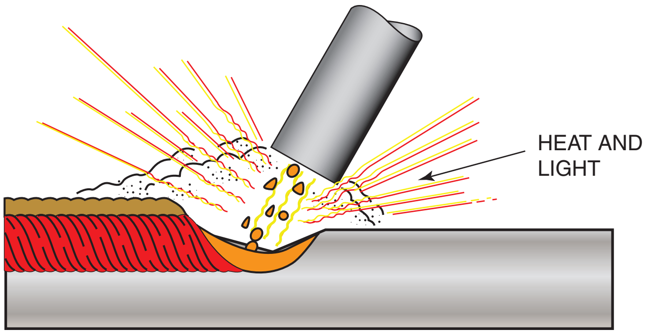


FIGURE 3-5 Energy is lost from the weld in the form of radiation and convection.

SMA Welding Arc Heat

The amount of heat produced by the arc is determined by the amperage. The higher the amperage setting, the higher the heat produced by the welding arc; the lower the amperage setting, the lower the heat produced. Each electrode diameter has a recommended minimum and maximum amperage range and, therefore, a recommended heat range. If you were to try to put too many amps through a small diameter electrode, it would overheat and could even melt. If the amperage setting is too low for an electrode diameter, then the end of the electrode may not melt evenly, if at all.

Not all of the heat produced by an arc reaches the weld. Some of the heat is radiated away in the form of light and heat waves, **Figure 3-5**. Some additional heat is carried away with the hot gases formed by the electrode covering. Heat is also lost through conduction in the work. In total, approximately 50% of all heat produced by an arc is missing from the weld.

Half of the remaining heat that the arc produces is not distributed evenly between both ends of the arc. This distribution depends on the composition of the electrode's coating and type of welding current.

Types of Welding Currents

The three different types of current used for welding are alternating current (AC), direct-current electrode negative (DCEN), and direct-current electrode positive (DCEP). The terms *DCEN* and *DCEP* have replaced the former terms *direct-current straight polarity* (*DCSP*) and *direct-current reverse polarity* (*DCRP*). DCEN and DCSP are the same currents, and DCEP and DCRP are the same currents. Some electrodes can be used with only one type of current. Others can be used with two or more types of current. Each welding current has a different effect on the weld.

DCEN In direct-current electrode negative, the electrode is negative and the work is positive, **Figure 3-6**. The electrons are leaving the electrode and traveling across the arc to the surface of the metal being welded. This results in approximately one-third of the welding heat on the electrode and two-thirds on the metal being welded. DCEN welding current produces a high electrode melting rate.

DCEP In direct-current electrode positive, the electrode is positive and the work is negative, **Figure 3-7**. The electrons are leaving the surface of the metal being welded and traveling across the arc to the electrode. This results in approximately two-thirds of the welding heat on the electrode and one-third on the metal being welded.

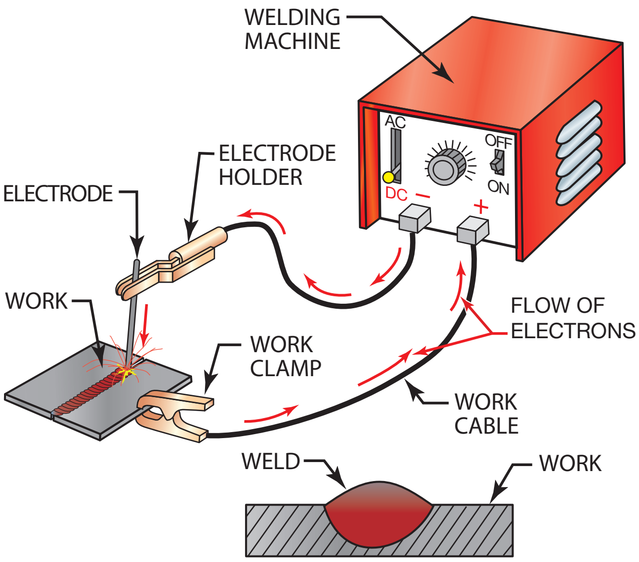


FIGURE 3-6 Electrode negative (DCEN), straight polarity (DCSP).

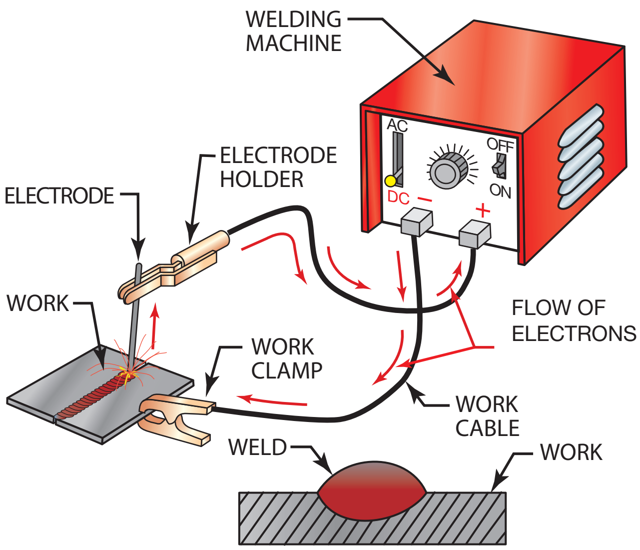


FIGURE 3-7 Electrode positive (DCEP), reverse polarity (DCRP).

AC In alternating current, the electrons change direction every 1/120 of a second so that the electrode and work alternate from **anode** to **cathode**, **Figure 3-8**. The positive side of an electrode arc is called the anode, and the negative side is called the cathode. The rapid reversal of the current flow causes the welding heat to be evenly distributed on both the work and the electrode—that is, half on the work and half on the electrode. The even heating gives the weld bead a balance between penetration and buildup, **Figure 3-9**.

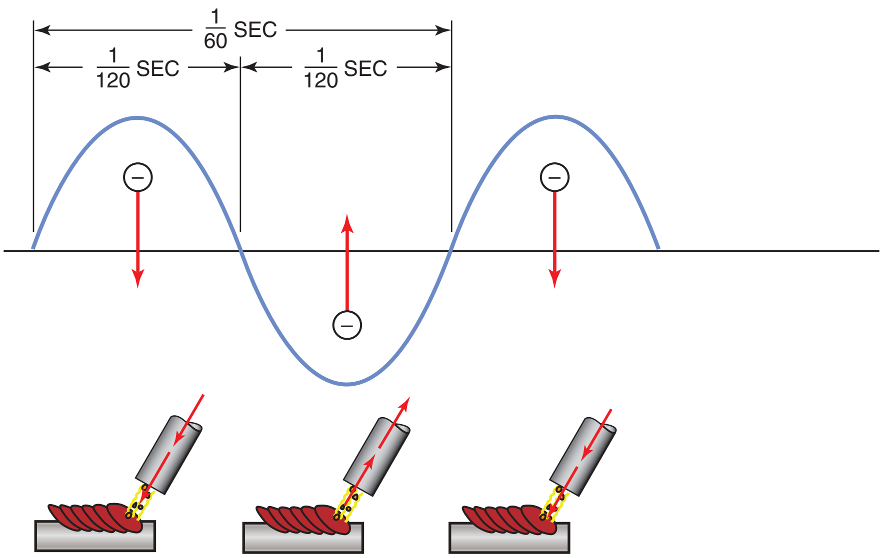


FIGURE 3-8 AC sign wave.

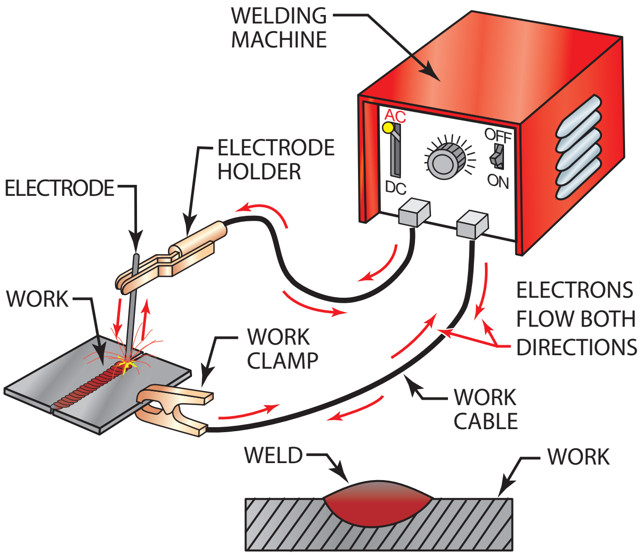


FIGURE 3-9 Alternating current (AC).

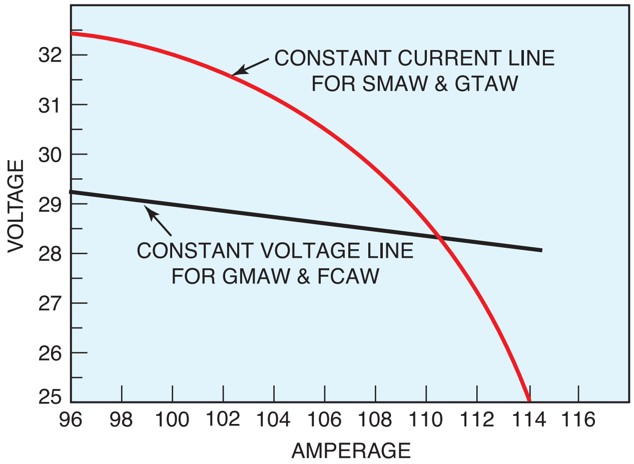


FIGURE 3-10 Constant voltage (CV) and constant current (CC).

TYPES OF WELDING POWER SUPPLIES (MACHINES)

Welding power can be supplied as

- Constant voltage (CV)—The arc voltage remains constant at the selected setting even if the arc length and amperage increase or decrease.
- Rising arc voltage (RAV)—The arc voltage increases as the amperage increases.
- Constant current (CC)—The total welding current (watts) remains the same. This type of power is also called drooping arc voltage (DAV) because the arc voltage decreases as the amperage increases.

The shielded metal arc welding (SMAW) process requires a constant current arc voltage characteristic, illustrated by the constant current line in **Figure 3-10**. The shielded metal arc welding machine's voltage **output** decreases as current increases. This output power source provides a reasonably high open circuit voltage before the arc is struck. The high open circuit voltage quickly stabilizes the arc. The arc voltage rapidly drops to the lower closed circuit level after the arc is struck. Following this short starting surge, the power (watts) remains almost constant despite the changes in arc length. With a constant voltage output, small changes in arc length would cause the power (watts) to make large swings. The welder would lose control of the weld.

Open Circuit Voltage

Open circuit voltage is the voltage at the electrode before striking an arc (with no current being drawn). The open circuit voltage is much like the higher surge of pressure you might observe when a water hose nozzle is first opened, **Figure 3-11A** and **Figure 3-11B**. It is easy to see that the initial pressure from the garden hose was higher than the pressure of the continuous flow of water. The open circuit

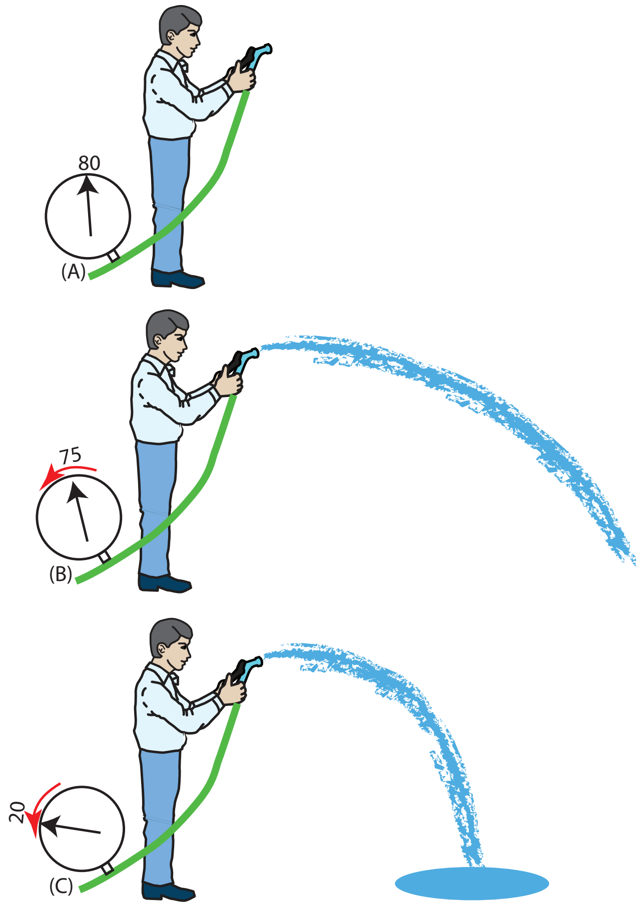


FIGURE 3-11 (A) Closed circuit pressure, (B) initial pressure surge, and (C) closed circuit pressure.

voltage is usually between 50 V and 80 V. The higher the open circuit voltage, the easier it is to strike an arc because of the initial higher voltage pressure.

CAUTION

The maximum safe open circuit voltage for welders is 80 V. The higher the voltage, the greater the chance of an electrical shock.

Operating Voltage

Operating, welding, or closed circuit voltage is the voltage at the arc during welding. **Operating voltage** is much like the water pressure observed as the water hose is being used, **Figure 3-11C**. The operating voltage will vary with arc length, type of electrode being used, type of current, and polarity. The welding voltage will be between 17 V and 40 V.

Arc Blow

When electrons flow, they create lines of magnetic force that circle around the path of flow, **Figure 3-12**. These lines of magnetic force are referred to as **magnetic flux lines**. They space themselves evenly along a current-carrying wire. If the wire is bent, then the flux lines on one side are compressed together, and those on the other side are stretched out, **Figure 3-13**. The unevenly spaced flux lines try to straighten the wire so that the lines can be evenly spaced once again. The force that they place on the wire is usually small, so the wire does not move. However, when welding with very high amperages, 600 amperes or more, the force may actually cause the wire to move.

The welding current flowing through a plate or any residual magnetic fields in the plate will result in unevenly spaced magnetic flux lines. These uneven flux lines can, in turn, cause the arc between the electrode and the work to move during welding. The term *arc blow* refers to this movement of the arc. Arc blow makes the arc drift like a string would drift in the wind. Arc blow can be more of a problem when the magnetic fields are the most uneven, such as when they are concentrated in corners, at the ends of plates, and when the work lead is connected to only one side of a plate, **Figure 3-14**.

The more complex a weldment becomes, the more likely arc blow will become a problem. Complex weldments can distort the magnetic lines of flux in unexpected ways. If you encounter severe arc blow during a weld, stop welding and take corrective measures to control or reduce the arc blow.

Controlling Arc Blow Arc blow can be controlled or reduced by connecting the work lead to the end of the weld joint, and then welding away from the work lead, **Figure 3-15**. Another way of controlling arc blow is to use two work leads, one on each side of the weld. The best way to eliminate arc blow is to use alternating current. Because alternating current changes directions, the flux lines do not become strong enough to bend the arc before the current changes direction. If it is impossible to move the work connection or to change to AC, a very short arc length can help control arc blow. A large tack weld or a change in the electrode angle can also help control arc blow.

Arc blow may not be a problem as you are learning to weld in the shop because most welding tables are all

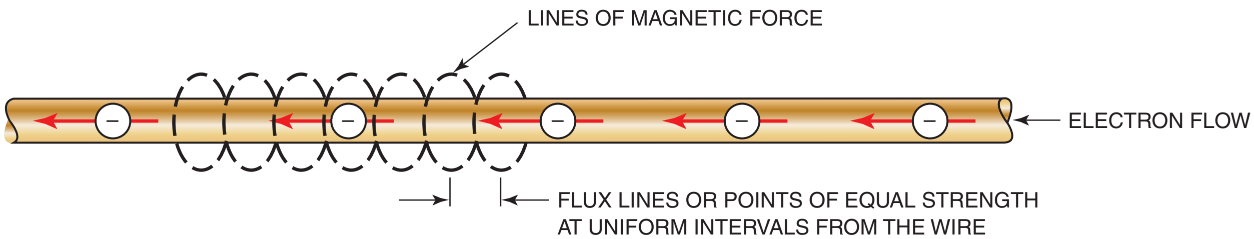


FIGURE 3-12 Magnetic force around a wire.

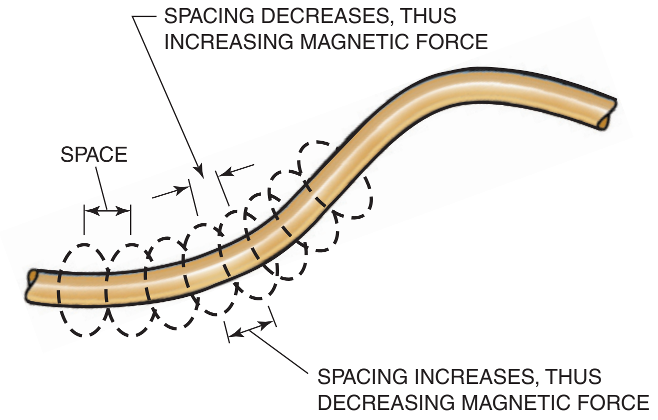


FIGURE 3-13 Magnetic forces concentrate around bends in wires.

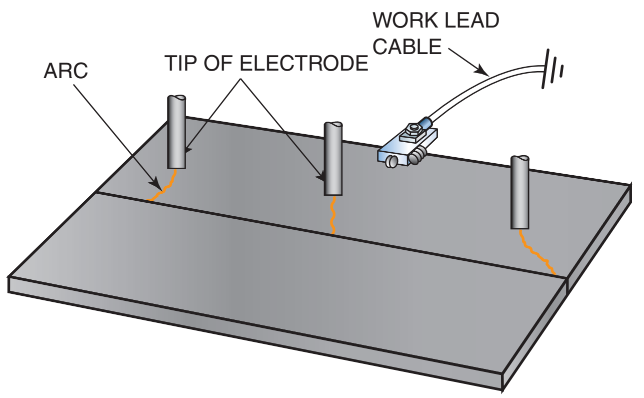


FIGURE 3-14 Arc blow.

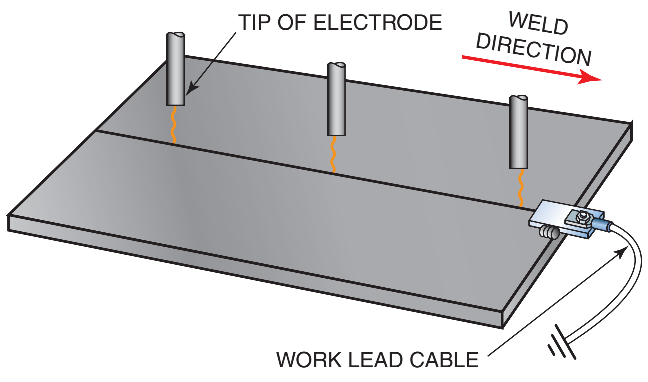


FIGURE 3-15 Correct current connections to control arc blow.

steel. However, if you are using a pipe stand to hold your welding practice plates, arc blow can become a problem. Try changing where you have your practice plates clamped to change the path the welding current takes through the plate, which can change the affects of arc blow.

Types of Power Sources

Two types of electrical devices can be used to produce the low-voltage, high-amperage current combination that arc welding requires. One type uses electric motors or internal combustion engines to drive alternators or generators. The other type uses step-down transformers. Because transformer-type welding machines are quieter, are more energy-efficient, require less maintenance, and are less expensive, they are now the industry standards. However, engine-powered generators are still widely used for portable welding.

Transformer-Type Welding Machines A welding transformer uses the alternating current (AC) supplied to the welding shop at a high voltage to produce the low-voltage welding power. The heart of these welders is the step-down transformer. All transformers have the following three major components:

- Primary coil—the winding attached to the incoming electrical power
- Secondary coil—the winding that has the electrical current induced and is connected to the welding lead and work leads
- Core—made of laminated sheets of steel and used to concentrate the magnetic field produced in the primary winding into the secondary winding, **Figure 3-16**

As electrons flow through a wire, they produce a magnetic field around the wire. If the wire is wound into a coil, the weak magnetic field of each wire is concentrated to produce a much stronger central magnetic force. Because the current being used is alternating or reversing each 1/120 of a second, the magnetic field is constantly being built and allowed to collapse. By placing a second or secondary winding of wire in the magnetic field produced by the first or primary winding, a current will be induced in the secondary winding. The placing

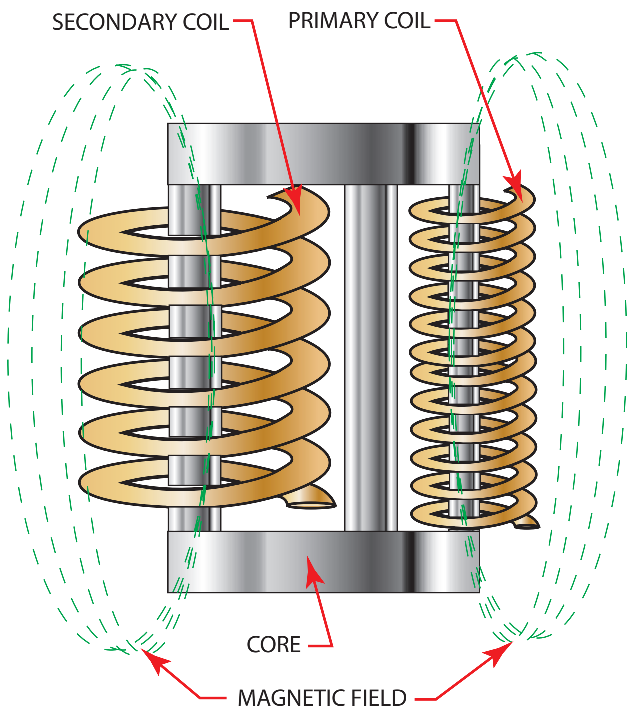


FIGURE 3-16 Parts of a step-down transformer.

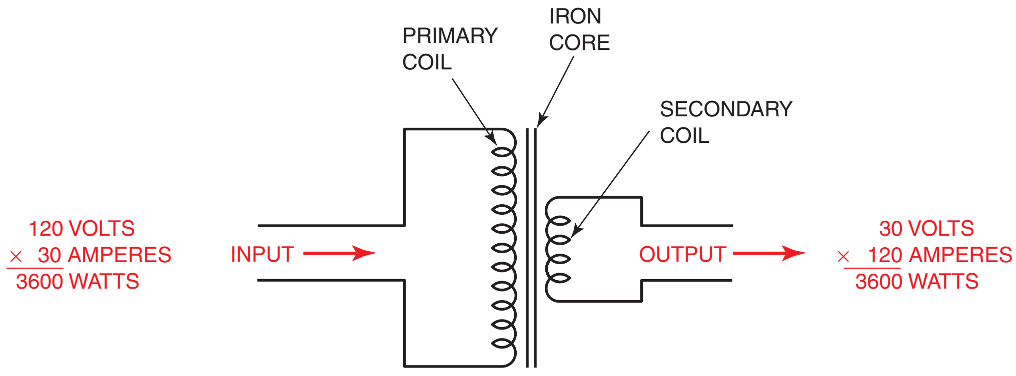


FIGURE 3-17 Diagram of a step-down transformer.

of an iron core in the center of these coils will increase the concentration of the magnetic field, **Figure 3-17**.

A transformer with more turns of wire in the primary winding than in the secondary winding is known as a **step-down transformer**. A step-down transformer takes a high-voltage, low-amperage current and changes it into a low-voltage, high-amperage current. Except for some power lost by heat within a transformer, the power (watts) into a transformer equals the power (watts) out because the volts and amperes are mutually increased and decreased.

A transformer welder is a step-down transformer. It takes the high line voltage (110 V, 220 V, 440 V, etc.) and low-amperage current (30 A, 50 A, 60 A, etc.) and changes it into 17 V to 45 V at 190 A to 590 A.

THINK GREEN

Conserve Electricity

Turn the power switch off any time you have stopped welding for a few minutes because electricity flows through the primary coil of a transformer-type welder any time the power switch is on, **Figure 3-18**. The amount of current flowing is not as much as it is when you are welding, but this practice will save electricity and can lengthen the life of your welding machine.

Welding machines can be classified by the method by which they control or adjust the welding current. The major classifications are multiple coil (called tap type), movable coil, movable core, (see Figure 3-18), and **inverter** type.

Multiple-Coil The multiple-coil machine, or tap-type machine, allows the selection of different current settings by tapping into the secondary coil at a different turn value. The greater the number of turns, the higher the amperage is induced in the turns. These machines may have a large number of fixed amperes, **Figure 3-19**, or they may have two or more amperages that can be adjusted further with a fine adjusting knob. The fine adjusting knob may be marked in amperes, or it may be marked in tenths, hundredths, or in any other unit.

Courtesy of Lincoln Electric Company

FIGURE 3-19 Tap-type transformer welding machine.

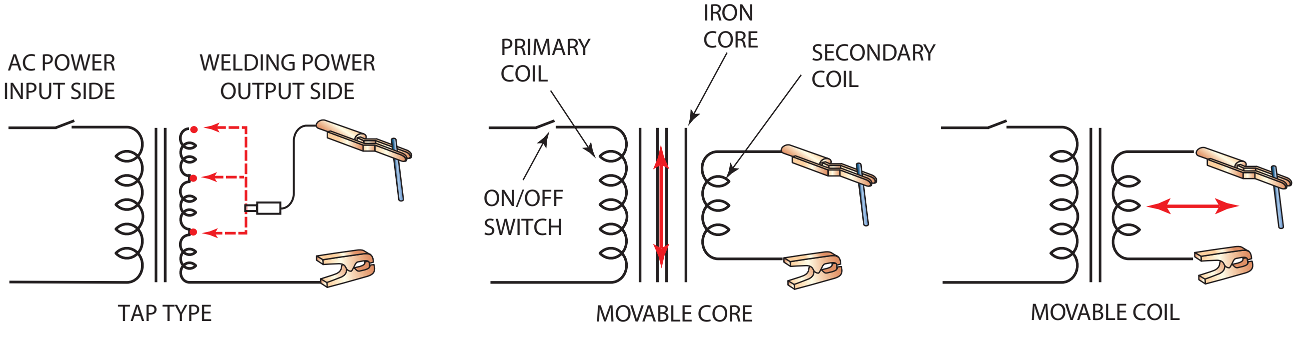


FIGURE 3-18 Major types of adjustable welding transformers.

EXPERIMENT 3-1

Estimating Amperages

Using a pencil and paper, you will prepare a rough estimate of the amperage setting of a welding machine listed in **Table 3-1**. **Figure 3-20** shows a welding machine with low, medium, and high tap amperage ranges. A fine adjusting knob is marked with 10 equal divisions, and each division is again divided by 10 smaller lines.

The machine is set on the medium range, 50 to 250 amperes, and the fine adjusting knob is turned until it points to the line marked 5 (halfway between 0 and 10). This means that the amperage is halfway from 50 to 250, or 150 amperes. If the fine adjusting knob points between 2 and 3, the resulting amperage is one-quarter of the way from 50 to 250, or approximately 100 amperes. If the knob points between 7 and 8, then the amperage is three-quarters of the way from 50 to 250, or approximately 200 amperes. If the knob points at 4, the amperage is more than 100 but a little less than 150, or approximately 130 to 140 amperes.

Because this is a method of estimating only, the amperage value obtained is close enough to allow an arc to be struck. The welder can then finish the fine adjusting knob to obtain a good weld.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

Number	Range Selected	Knob Pointed	Estimated Amperage
1	Medium	6	________
2	Medium	10	________
3	Medium	Between 1 & 2	________
4	Low	5	________
5	Low	3	________
6	Low	Between 9 & 10	________
7	High	4	________
8	High	9	________
9	High	8	________
10	High	Between 5 & 6	________

TABLE 3-1 Estimate the Amperage for the Welding Machine Settings

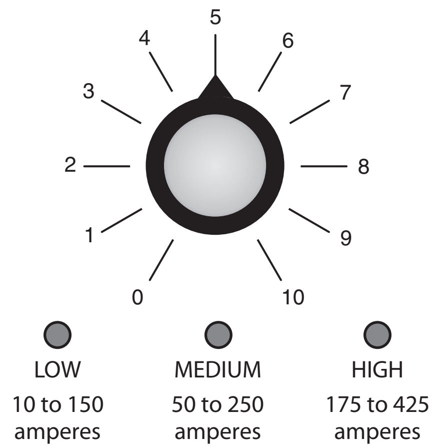


FIGURE 3-20 Welder power range taps and adjustment knob.

EXPERIMENT 3-2

Calculating the Amperage Setting

Using a pencil and paper or calculator, you will calculate the exact value for each space on the fine adjusting knob of a welding machine as listed in **Table 3-2**.

With the machine set on the medium range, from 50 to 250 amperes, first subtract the low amperage from the high amperage to get the amperage spread ($250 - 50 = 200$). Now divide the amperage spread by the number of units shown on the fine adjusting knob ($200 \div 10 = 20$). Each unit is equal to a 20-ampere increase, **Table 3-3**. When the knob points to 0, the amperage is 50; when the knob points to 1, the amperage is 70; and at 2, the amperage is 90, **Figure 3-21**. There are 100 small units on the fine adjusting knob. Dividing the amperage spread by the number of small units gives the amperage value for each unit ($200 + 100 = 2$). Therefore, if the knob points to 6.1, the amperage is set at a value of $50 + 120 + 2 = 172$ amperes. This method provides a good starting place for the current setting, but if the welding is to be made in accordance with a welding procedure's specific amperage setting, it will be necessary to use a calibrated meter to make the correct setting.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

Number	Setting	Value in Amperes
1	0 = ______ + ______	or ________
2	1 = ______ + ______	or ________
3	2 = ______ + ______	or ________
4	3 = ______ + ______	or ________
5	4 = ______ + ______	or ________
6	5 = ______ + ______	or ________
7	6 = ______ + ______	or ________
8	7 = ______ + ______	or ________
9	8 = ______ + ______	or ________
10	9 = ______ + ______	or ________
11	10 = ______ + ______	or ________

TABLE 3-2 The Machine Is Set on the High Amperage Range of 125 to 350

Setting	Value in Amperes
0 = 50 + 0,	or 50 A
1 = 50 + 20,	or 70 A
2 = 50 + 40,	or 90 A
3 = 50 + 60,	or 110 A
4 = 50 + 80,	or 130 A
5 = 50 + 100,	or 150 A
6 = 50 + 120,	or 170 A
7 = 50 + 140,	or 190 A
8 = 50 + 160,	or 210 A
9 = 50 + 180,	or 230 A
10 = 50 + 200,	or 250 A

TABLE 3-3 Example of a Table Used to Calculate the Amperage Setting

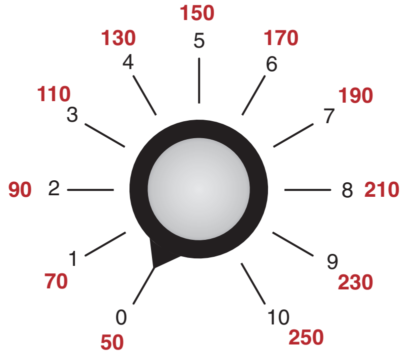


FIGURE 3-21 Fine adjusting knob.

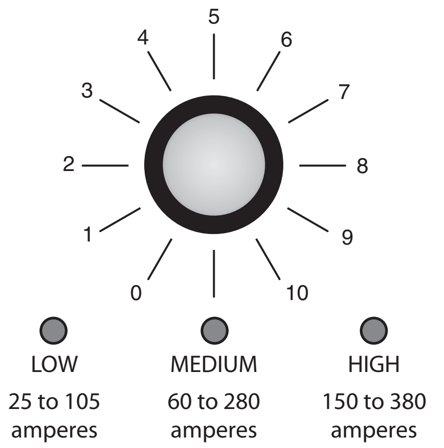


FIGURE 3-22 Practice 3-1.

Number	Knob Setting	Value in Amperes
1	1	________
2	4	________
3	5	________
4	7	________
5	3	________
6	9	________
7	2.3	________
8	5.7	________
9	8.5	________
10	9.1	________

TABLE 3-4 Calculate the Amperage for Each of the Knob Settings

PRACTICE 3-1

Estimating Amperages

Using a pencil and paper and the amperage ranges given in this practice (or from machines in the shop), you will estimate the amperage when the knob is at the one-quarter, one-half, and three-quarter settings, **Figure 3-22**.

Complete a copy of the “Student Welding Report” listed in Appendix I or provided by your instructor. ◆

PRACTICE 3-2

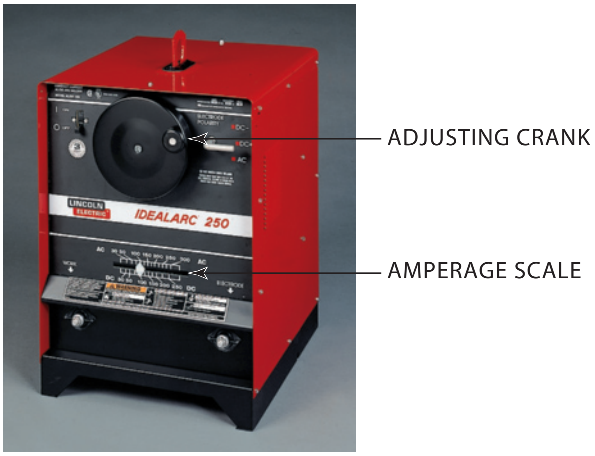
Calculating Amperages

Using a pencil and paper or a calculator, and the amperage ranges given in this practice (or from machines in the shop), you will calculate the amperages for each of the knob settings in **Table 3-4**.

Complete a copy of the “Student Welding Report” listed in Appendix I or provided by your instructor. ◆

MOVABLE COIL OR CORE

Movable coil or movable core machines are adjusted by turning a handwheel that moves the internal parts closer together or farther apart. The adjustment may also be made by moving a lever or turning a knob, **Figure 3-23**. These machines may have a high range and low range, but they do not have a fine adjusting knob. The closer the primary and secondary coils are, the greater the induced current; the greater the distance between the coils, the smaller the induced current, **Figure 3-24**. Moving the core in concentrates more of the magnetic force on the secondary coil, thus increasing the current. Moving the core out allows the field to disperse, and the current is reduced, **Figure 3-25**.



Courtesy of Lincoln Electric Company

FIGURE 3-23 A movable, core-type welding machine.

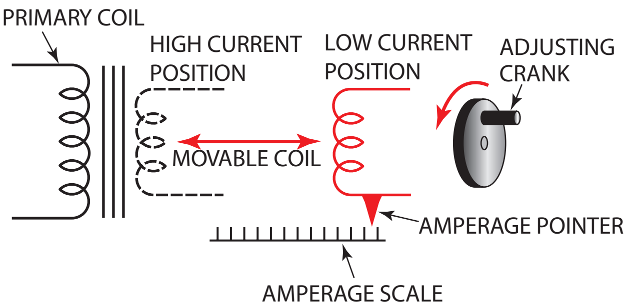


FIGURE 3-24 Movable coil.

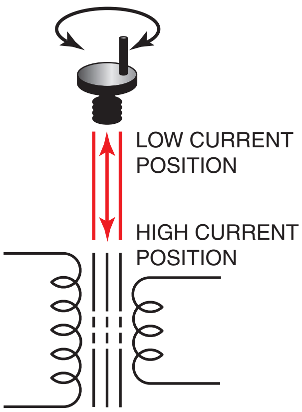


FIGURE 3-25 Movable core.

Larry Jeffus

FIGURE 3-26 This 95-amp inverter SMA-GTA welder weighs less than 9 pounds and fits into its own briefcase-size carrier.

INVERTER

Inverter welding machines are much smaller than other types of machines of the same amperage range. This smaller size makes the welder much more portable as well as increases the energy efficiency, **Figure 3-26**. In a standard welding transformer, the iron core used to concentrate the magnetic field in the coils must be sized to work in harmony with the 60 cycle power. When the iron core is sized correctly, the magnetic field will build and collapse smoothly. An inverter welder uses solid-state electronic parts to change the incoming power from 60 cycles per second to several thousand cycles per second. This higher frequency allows the transformer to build and collapse the magnetic field much faster in a much lighter transformer. Inverter transformers may be as light as 7 lb (3 kg) and still do the work of a standard welding machine transformer weighing 100 lb (45 kg) or more. Additional electronic parts in the inverter welder remove the high frequency to turn the output into smooth DC welding power.

The use of electronics in the inverter-type welder allows it to produce any desired type of welding power. Before the invention of this machine, each type of welding required a separate machine. Now, a single welding machine can produce the specific type of current needed for shielded metal arc welding, gas tungsten arc welding, gas metal arc welding, and plasma arc cutting. Because the machine can be light enough to be carried closer to work, shorter welding cables can be used. The welder does not have to walk as far to adjust the machine. In fact, some inverter welding machines allow the welder to make changes in the welding setting using a remote controller. Welding machine power

wire is cheaper than welding cables. Some manufacturers produce machines that can be stacked so that when you need a larger machine, all you have to do is add another unit to your existing welder.

GENERATOR-TYPE AND ALTERNATOR-TYPE WELDERS

Generators and alternators both produce welding electricity from a mechanical power source. Both devices have an armature that rotates and a stator that is stationary. As a wire moves through a magnetic force field, electrons in the wire are made to move, producing electricity.

In an alternator, magnetic lines of force rotate inside a coil of wire, **Figure 3-27**. An alternator can produce AC only. In a generator, a coil of wire rotates inside a magnetic field. A generator produces DC. It is possible for alternators to use diodes to change the AC to DC for welding. In generators, the welding current is produced on the armature and is picked up with brushes, **Figure 3-28**. In alternators, the welding current is produced on the stator, and only the small current for the electromagnetic force field goes across the brushes. Therefore, the brushes in an alternator are smaller and last longer. Alternators can be smaller in size and lighter in weight than generators and still produce the same amount of power.

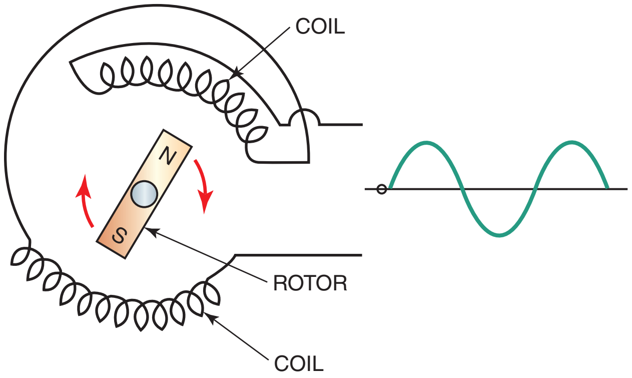


FIGURE 3-27 Schematic diagram of an alternator.

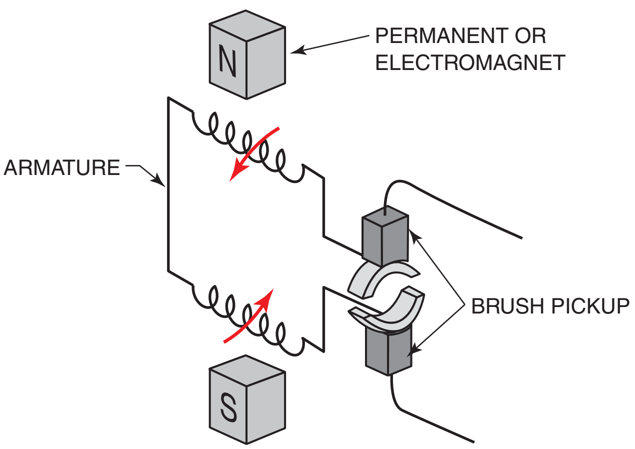
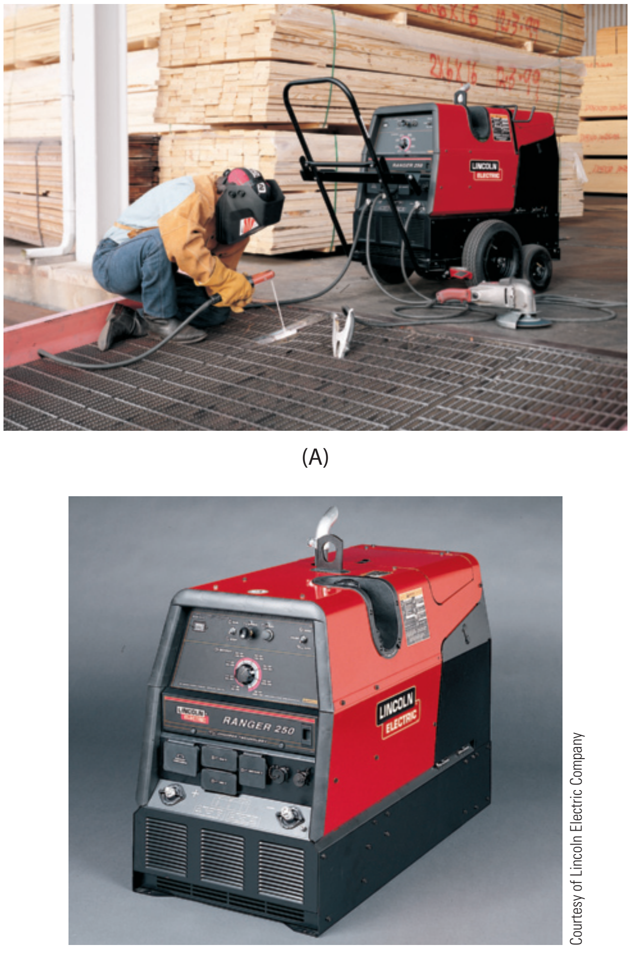


FIGURE 3-28 Diagram of a generator.

Engine-driven generators and alternators may run at the welding speed all the time, or they may have an option that reduces their speed to an idle when welding stops. This option saves fuel and reduces wear on the welding machine. To strike an arc when using this type of welder, stick the electrode to the work for a second. When you hear the welding machine (welder) pick up speed, remove the electrode from the work and strike an arc. In general, the voltage and amperage are too low to start a weld, so shorting the electrode to the work should not cause the electrode to stick. A timer can be set to control the length of time that the welder maintains speed after the arc is broken. The time should be set long enough to change electrodes without losing speed.

Portable welders often have 110-volt or 220-volt plug outlets, which can be used to run grinders, drills, lights, plasma cutting equipment, air compressors, and other equipment a welder may need. The power provided may be AC or DC. If DC is provided, then only equipment with brush-type motors or tungsten lightbulbs can be used. If the plug is not specifically labeled 110 volts AC, check the owner's manual before using it for devices such as radios or other electronic equipment. Typical portable welders are shown in **Figure 3-29A** and **Figure 3-29B**.



Courtesy of Lincoln Electric Company

(A)

Courtesy of Lincoln Electric Company

(B)

FIGURE 3-29 (A) Portable engine generator welder. (B) Light weight portable SMA and GTA welder.

ROUTINE MAINTENANCE

One of the major drawbacks to portable engine-driven welders is that they require more maintenance than do the other types of welding machines. Poor maintenance practices can lead to a variety of problems, including starting and running difficulties, failure to maintain consistent welding power, higher operating cost, and significantly reduced engine life.

THINK GREEN
Reduce Air Pollution

It is important to keep portable engine welders properly tuned so they do not produce excessive air pollution. A properly maintained engine will produce less air pollution and burn less fuel.

THINK GREEN
Recycle Used Oil and Batteries

Both used engine oil and batteries can be recycled. Used oil can be re-refined so it can be used again, and the lead and other parts of used batteries can be recycled to make new ones.

It is recommended that a routine maintenance schedule for portable welders should be set up and followed. By checking the oil, coolant, battery, filters, fuel, and other parts, the life of the equipment can be extended. A checklist can be posted on the welder, **Table 3-5**.

Check Each Day before Starting
Oil level
Water level
Fuel level
Check Each Monday
Battery level
Cables
Fuel line filter
Check at Beginning of Month
Air filter
Belts and hoses
Change oil and filter
Check Each Fall
Antifreeze
Test battery
Pack wheel bearings
Change gas filter

TABLE 3-5 Portable Welder Checklist. The Owner's Manual Should Be Checked for Any Additional Items that Might Need Attention

CONVERTING AC TO DC

Alternating welding current can be converted to direct current by using a series of rectifiers. A **rectifier** allows current to flow in one direction only, **Figure 3-30**.

If one rectifier is added, then the welding power appears as shown in **Figure 3-31**. It would be difficult to weld with pulsating power such as this. A series of rectifiers, known as a bridge rectifier, can modify the alternating current so that it appears as shown in **Figure 3-32**.

Rectifiers become hot as they change AC to DC. They must be attached to a heat sink and cooled by having air blown over them. The heat produced by a rectifier reduces the power efficiency of the welding machine. **Figure 3-33** shows the amperage dial of a typical machine. Notice that at the same dial settings for AC and DC, the DC is at a lower amperage. The difference in amperage (power) is due to heat lost in the rectifiers. The loss in power makes operation with AC more efficient and less expensive compared to DC.

A DC adapter for small AC machines is available from manufacturers. For some types of welding, AC does not work properly.

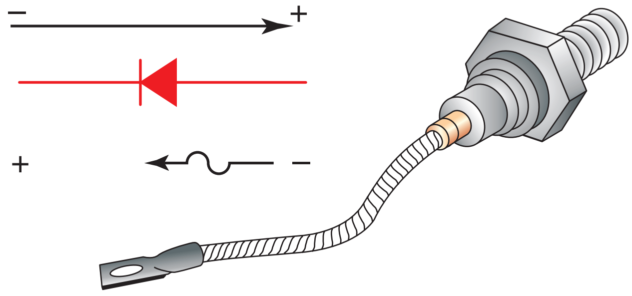


FIGURE 3-30 Rectifier.

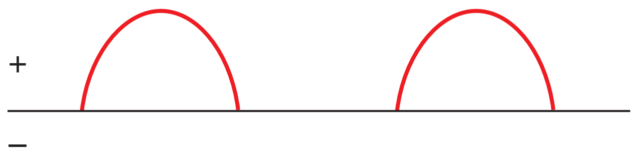


FIGURE 3-31 One rectifier in a welding power supply results in pulsating power.

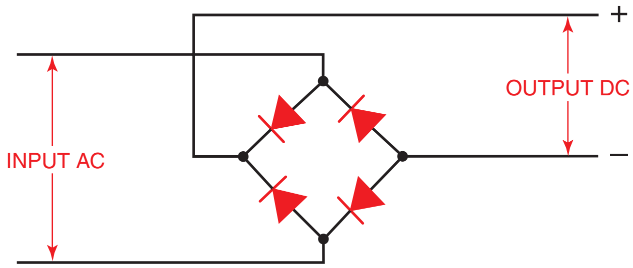


FIGURE 3-32 Bridge rectifier.

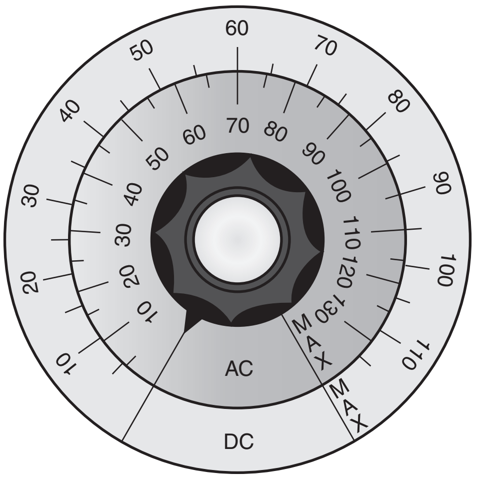


FIGURE 3-33 Typical dial on an AC-DC transformer rectifier welder.

DUTY CYCLE

Welding machines produce internal heat at the same time they produce the welding current. Except for automatic welding machines, welders are rarely used every minute for long periods of time. The welder must take time to change electrodes, change positions, or change parts. Shielded metal arc welding never continues for long periods of time.

The **duty cycle** is the percentage of time a welding machine can be used continuously. A 60% duty cycle means that out of any 10 minutes, the machine can be used for a total of six minutes at the maximum rated current. When providing power at this level, it must be cooled off for four minutes out of every 10 minutes. The duty cycle increases as the amperage is lowered and decreases for higher amperages, **Figure 3-34**. Most welding machines weld at a 60% rate or less. Therefore, most manufacturers list the amperage rating for a 60% duty cycle on the nameplate that is attached to the machine. Other duty cycles are given on a graph in the owner's manual.

The manufacturing cost of power supplies increases in proportion to their rated output and duty cycle. To reduce their price, it is necessary to reduce either their rating or their duty cycle. For this reason, some home-hobby welding machines may have duty cycles as low as 20% even at a low welding setting of 90 to 100 amperes. The duty cycle on these machines should never be exceeded because a buildup of the internal temperature can cause the transformer insulation to break down, damaging the power source.

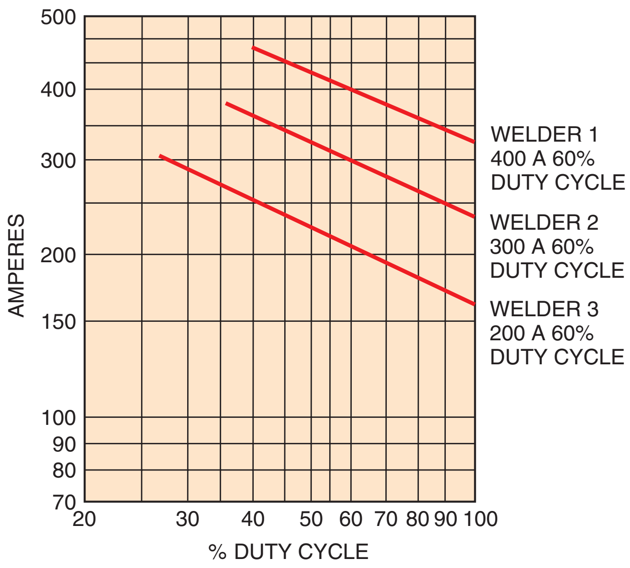


FIGURE 3-34 Duty cycle of a typical shielded metal arc welding machine.

PRACTICE 3-3

Reading the Duty Cycle Chart

Using a pencil and paper and the duty cycle chart in Figure 3-34 (or one from machines in the shop), you will determine the following:

Welder 1: Maximum welding amperage percent duty cycle at maximum amperage
Welder 2: Maximum welding amperage percent duty cycle at maximum amperage
Welder 3: Maximum welding amperage percent duty cycle at maximum amperage
Welder 1: Maximum welding amperage at 100% duty cycle
Welder 2: Maximum welding amperage at 100% duty cycle
Welder 3: Maximum welding amperage at 100% duty cycle

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

WELDER ACCESSORIES

A number of items must be used with a welding machine to complete the setup. The major items are the welding cables, the electrode holders, and the work clamps.

WELDING CABLES

The terms **welding cables** and **welding leads** mean the same thing. Cables to be used for welding must be flexible, well-insulated, and the correct size for the job. Most welding cables are made from stranded copper wire. Some manufacturers sell a newer type of cable made from aluminum wires. The aluminum wires are lighter and less expensive than copper. Because aluminum as a conductor is not as good as copper for a given wire size, the aluminum wire should be one size larger than would be required for copper.

The insulation on welding cables will be exposed to hot sparks, flames, grease, oils, sharp edges, impact, and other

Copper Welding Lead Sizes										
Amperes		100	150	200	250	300	350	400	450	500
Length of Cable ft	m									
50	15	2	2	2	2	1	1/0	1/0	2/0	2/0
75	23	2	2	1	1/0	2/0	2/0	3/0	3/0	4/0
100	30	2	1	1/0	2/0	3/0	4/0	4/0		
125	38	2	1/0	2/0	3/0	4/0				
150	46	1	2/0	3/0	4/0					
175	53	1/0	3/0	4/0						
200	61	1/0	3/0	4/0						
250	76	2/0	4/0							
300	91	3/0								
350	107	3/0								
400	122	4/0								

Aluminum Welding Lead Sizes										
Amperes		100	150	200	250	300	350	400	450	500
Length of Cable ft	m									
50	15	2	2	1/0	2/0	2/0	3/0	4/0		
75	23	2	1/0	2/0	3/0	4/0				
100	30	1/0	2/0	4/0						
125	38	2/0	3/0							
150	46	2/0	3/0							
175	53	3/0								
200	61	4/0								
225	69	4/0								

TABLE 3-6 Copper and Aluminum Welding Lead Sizes

types of wear. To withstand such wear, welding cables are manufactured with special insulation for that type of service.

As electricity flows through a cable, the resistance to the flow causes the cable to heat up and increase the voltage drop. To minimize the loss of power and prevent overheating, the electrode cable and work cable must be the correct size. **Table 3-6** lists the minimum size cable that is required for each amperage and length. Large welding lead sizes make electrode manipulation difficult. Smaller cable can be spliced to the electrode end of a large cable to make it more flexible. This whip-end cable must not be less than 10 ft (3 m) long.

CAUTION

A splice in a cable should not be within 10 ft (3 m) of the electrode because of the possibility of electrical shock.

PRACTICE 3-4

Determining Welding Lead Sizes

Using a pencil and paper and Table 3-6, "Copper and Aluminum Welding Lead Sizes," you will determine the following:

1. The minimum copper welding lead size for a 200-amp welder with 100-ft (30-m) leads
2. The minimum copper welding lead size for a 125-amp welder with 225-ft (69-m) leads
3. The maximum length aluminum welding lead that can carry 300 amps

Splices and end lugs are available from suppliers. Be sure that a good electrical connection is made whenever splices or lugs are used. A poor electrical connection will result in heat buildup, voltage drop, and poor service from the cable. Splices and end lugs must be well-insulated against possible electrical shorting, **Figure 3-35**.

Courtesy of ESAB Welding & Cutting Products

FIGURE 3-35 Power lug protection is provided by insulators.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

ELECTRODE HOLDERS

The electrode holder should be of the proper amperage rating and in good repair for safe welding. Electrode holders are designed to be used at their maximum amperage rating or less. Higher amperage values will cause the holder to overheat and burn up. If the holder is too large for the amperage range being used, manipulation is difficult and operator fatigue increases. Make sure that the correct amperage holder is chosen, **Figure 3-36**.

CAUTION

Never dip a hot electrode holder in water to cool it off. The problem causing the holder to overheat should be repaired.

A properly sized electrode holder can overheat if the jaws are dirty or loose, or if the cable is loose. If the holder heats up, then welding power is being lost. In addition, a hot electrode holder is uncomfortable to work with.

Replacement springs, jaws, insulators, handles, screws, and other parts are available to keep the holder in good working order, **Figure 3-37**. To prevent excessive damage to the holder, welding electrodes should not be burned too short. A 2-in. (50-mm) electrode stub is short enough to minimize electrode waste and save the holder.

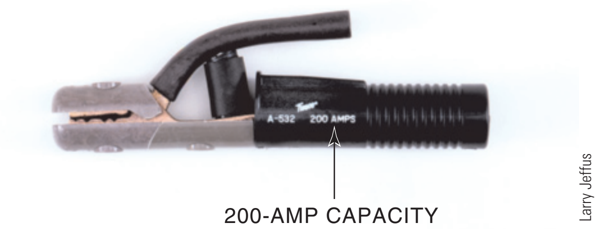


FIGURE 3-36 The amperage capacity of an electrode holder is often marked on its side.

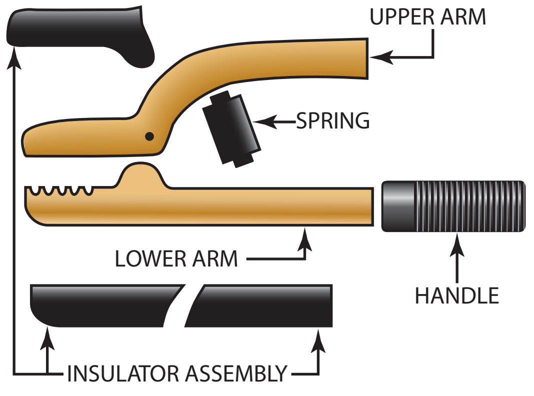


FIGURE 3-37 Replaceable parts of an electrode holder.

PRACTICE 3-5

Repairing Electrode Holders

Using the manufacturer's instructions for your type of electrode holder, required hand tools, and replacement parts, you will do the following:

CAUTION

Before starting any work, make sure that the power to the welder is off and locked off or that the welding lead has been removed from the machine.

1. Remove the electrode holder from the welding cable.
2. Remove the jaw insulating covers.
3. Replace the jaw insulating covers.
4. Reconnect the electrode holder to the welding cable.
5. Turn on the welding power or reconnect the welding cable to the welder.
6. Make a weld to ensure that the repair was made correctly.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

WORK CLAMPS

The work clamp must be the correct size for the current being used, and it must clamp tightly to the material. Heat can build up in the work clamp, reducing welding efficiency, just as was previously described for the electrode holder. Power losses in the work clamp are often overlooked. The clamp should be carefully touched occasionally to find out if it is getting hot.

In addition to power losses due to poor work lead clamping, a loose clamp may cause arcing that can damage a part. If the part is to be moved during welding, then a swivel-type work clamp may be needed, **Figure 3-38**.

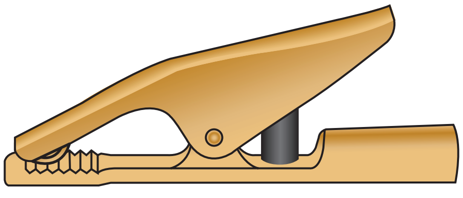


FIGURE 3-38 A work clamp may be attached to the workpiece.

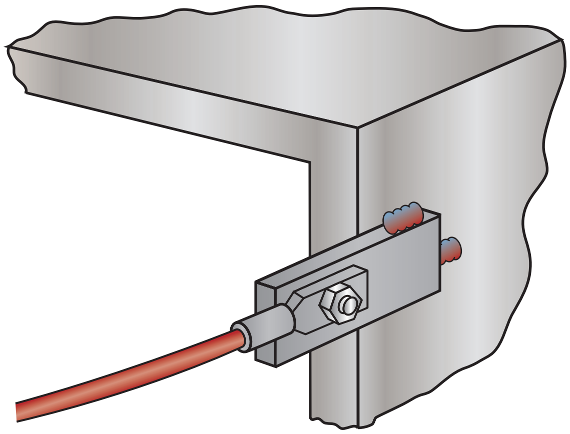


FIGURE 3-39 Tack welded ground to part.

It may be necessary to weld a tab to thick parts so that the work lead can be clamped to the tab, **Figure 3-39**.

EQUIPMENT SETUP

Arc welding machines should be located near the welding site, but far enough away so that they are not covered with spark showers. The machines may be stacked to save space, but there must be enough room between the machines to ensure the air can circulate and to keep the machines from overheating. The air that is circulated through the machine should be as free as possible of dust, oil, and metal filings. Even in a good location, the power should be turned off periodically and the machine should be blown out with compressed air, **Figure 3-40**.

The welding machine should be located away from cleaning tanks and any other sources of corrosive fumes

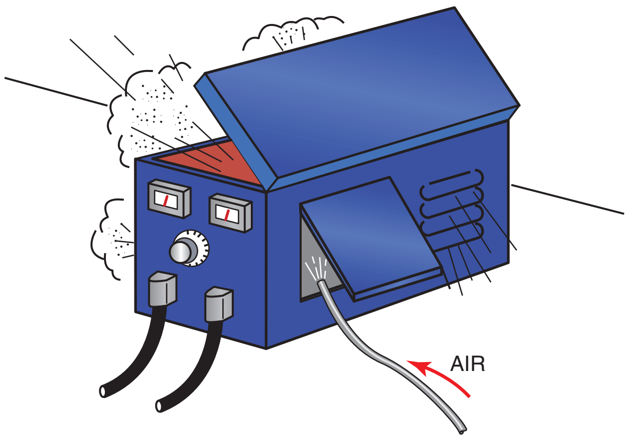


FIGURE 3-40 Slag, chips from grinding, and dust must be blown out occasionally so that they will not start a fire or cause a short-out or other types of machine failure.

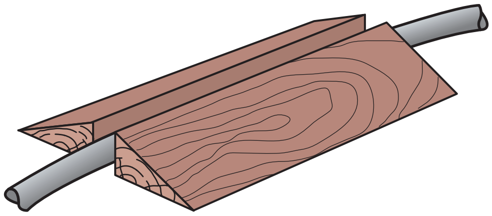


FIGURE 3-41 To prevent people from tripping when cables must be placed in walkways, lay two blocks of wood beside the cables.

that could be blown through it. Water leaks must be fixed and puddles must be cleaned up before a machine is used.

Power to the machine must be fused, and a power shut-off switch must be provided. The switch must be located so that it can be reached in an emergency without touching either the machine or the welding station. The machine case or frame must be grounded.

The welding cables should be sufficiently long to reach the workstation but not so long that they must always be coiled. Cables should not be placed on the floor in aisles or walkways. If cables must cross a walkway, then the cable must be installed overhead, or it must be protected by a ramp, **Figure 3-41**. The welding machine and its main power switch should be turned off and locked off while a person is installing or working on the cables.

The workstation must be free of combustible materials. Screens or curtains should be provided to protect other workers from the arc light.

The welding cable should never be wrapped around arms, shoulders, waist, or any other part of the body. If the cable was caught by any moving equipment, such as a forklift, crane, or dolly, a welder could be pulled off balance or more seriously injured. If it is necessary to hold the weight off the cable so that the welding can be more easily done, a free hand can be used. The cable should be held so that if it is pulled it can be easily released.

CAUTION

The cable should never be tied to scaffolding or ladders. If the cable is caught by moving equipment, the scaffolding or ladder may be upset, causing serious personal injury.

Check the surroundings before starting to weld. If heavy materials are being moved in the area around you, there should be a safety watch. A safety watch can warn a person of danger while that person is welding.

Summary

Understanding the scientific theory of electricity and magnetism aids you in understanding how the welding currents are produced and their reactions to changes in their physical surroundings. Understanding electromagnetic phenomena aids you in controlling arc blow. Failure to control arc blow can result in weld failures. In addition, understanding electricity helps you interpret information given on manufacturers' tables, charts, and equipment specifications.

Before starting any new job or welding operation, be sure to check the equipment manufacturer's safety guidelines for proper operation and maintenance. Follow all recommended guidelines. Keeping your work area clean and orderly helps prevent accidents.

Review

1. Describe the relation between voltage and amperage for welding current.
2. What produces the heat during a shielded metal arc weld?
3. Voltage can be described as ___.
4. Amperage can be described as ___.
5. Wattage can be described as ___.
6. What determines the exact temperature of the shielded metal welding arc?
7. Does all of the heat produced by an SMA weld stay in the weld? Why or why not?
8. What do the following abbreviations mean: AC, DCEN, DCEP, DCSP, and DCRP?
9. Sketch a welding machine, an electrode lead, an electrode holder, an electrode, a work lead, and work connected for DCEN welding.
10. Sketch a welding machine, an electrode lead, an electrode holder, an electrode, a work lead, and work connected for DCEP welding.
11. Why is SMA welding current referred to as *constant current*?
12. What is the higher voltage at the electrode before the arc is struck called? What is its advantage to welding?
13. Referring to the graph in Figure 3-9, what would the voltage be for the CC power supply at 110 amps? What would the watts be?
14. How does arc blow affect welding?
15. How can arc blow be controlled?
16. How does a welding transformer work?
17. What are *taps* on a welding transformer?
18. What would the approximate amperage setting be if a welder were set to the high range (150 to 350 amps) and the fine adjustment knob were pointing at 5 on a 10-point scale?
19. What are the advantages of the inverter-type welding power supply?
20. What is the difference between the welding current produced by alternators and by generators?
21. What are the advantages of alternators over generators?
22. What must be checked before using the 110-volt power plug on a portable welder?
23. What is meant by a welder's *duty cycle*?
24. Why must a welding machine's duty cycle never be exceeded?
25. Why is copper better than aluminum for welding cables?
26. A splice in a welding cable should never be any closer than ___ to the electrode holder.
27. Why must the electrode holder be correctly sized?
28. What can cause a properly sized electrode holder to overheat?
29. What problem can occur if welding machines are stacked or placed too closely together?
30. Why must welding cables never be tied to scaffolding or ladders?

Chapter 4

Shielded Metal Arc Welding of Plate

OBJECTIVES

After completing this chapter, the student should be able to

- demonstrate safe work practices.
- demonstrate the ability to strike an arc at a specific point.
- list the problems that can result if the welding current is set too low or too high.
- discuss how to select the correct diameter of a welding electrode for a weld.
- describe the effects of overheating a weld by comparing the bead's shape for width, reinforcement, and appearance.
- define *arc length* and describe the effects of using too short or too long of an arc length.
- compare a leading electrode angle to a trailing electrode angle.
- tell what characteristics of the weld bead can be controlled by the movement or weaving of the welding electrode.
- discuss the importance of positioning the welder and the plate properly before starting to weld.
- give the characteristics of the three filler metal groups E6010 and E6011, E6012 and E6013, and E7016 and E7018.
- define *stringer beads* and tell how they are used.
- demonstrate the ability to make welds on various joints in all positions.

KEY TERMS

amperage range
arc length
cellulose-based fluxes
chill plate
electrode angle
lap joint
mineral-based flux
rutile-based fluxes
square butt joint
stringer bead
tee joint
travel angle
weave pattern
work angle

INTRODUCTION

Shielded metal arc welding (SMAW), or stick welding, is a common method used to join plates. This method provides a high temperature and concentration of heat, which allows a small molten weld pool to be built up quickly. The addition of filler metal from the electrode adds reinforcement and increases the strength of the weld. SMAW can be performed on almost any type of metal 1/8 in. (3 mm) thick or thicker. A minimum amount of equipment is required, and it can be portable.

High-quality welds can be consistently produced on almost any type of metal, any shape, and in any position. The quality of the welds produced depends largely on the skill of the welder. Developing the necessary skill level requires practice. However, practicing the welds repeatedly without changing techniques will not aid in developing the required skills. Each time a weld is completed it should be evaluated, and then a change should be made in the technique to improve the next weld.

PRACTICE 4-1

Shielded Metal Arc Welding Safety

Using a welding workstation, welding machine, welding electrodes, welding helmet, eye and ear protection, welding gloves, proper work clothing, and any special protective clothing that may be required, demonstrate to your instructor and other students the safe way to prepare yourself and the welding workstation for welding. Include in your demonstration appropriate references to burn protection, eye and ear protection, material specification data sheets, ventilation, electrical safety, general work clothing, special protective clothing, and area cleanup.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 4-2

Striking the Arc

Using a properly set-up and adjusted arc welding machine, the proper safety protection, as demonstrated in Practice 4-1, E6011 welding electrodes with 1/8 in. (3 mm) diameter, and one piece of mild steel plate 1/4 in. (6 mm) thick, you will practice striking an arc, **Figure 4-1**.

With the electrode held over the plate, lower your helmet. Scratch the electrode across the plate (like striking a large match), **Figure 4-2**. As the arc is established, slightly raise the electrode to the desired arc length. Hold the arc in one place until the molten weld pool builds to the desired size. Slowly lower the electrode as it burns off and move it forward to start the bead.

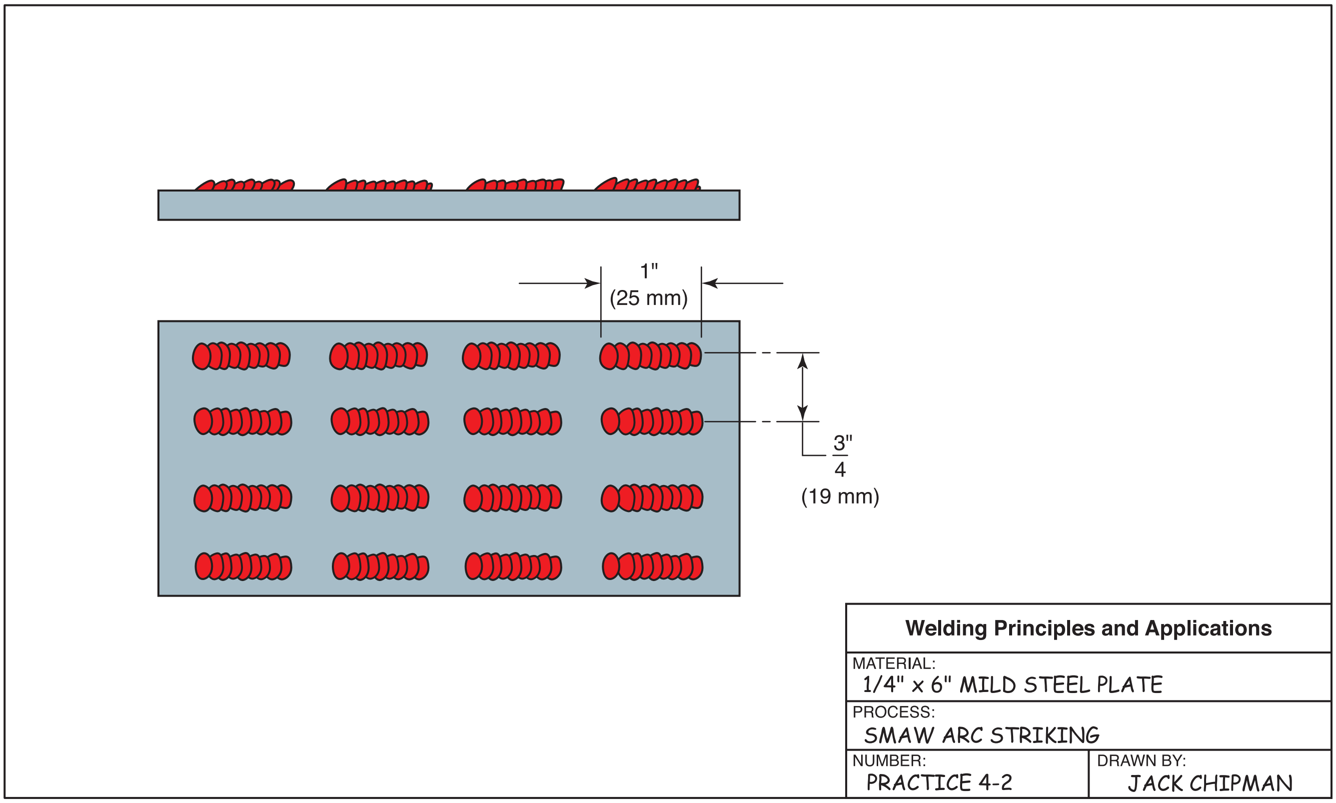


FIGURE 4-1 Striking an arc and running short beads.

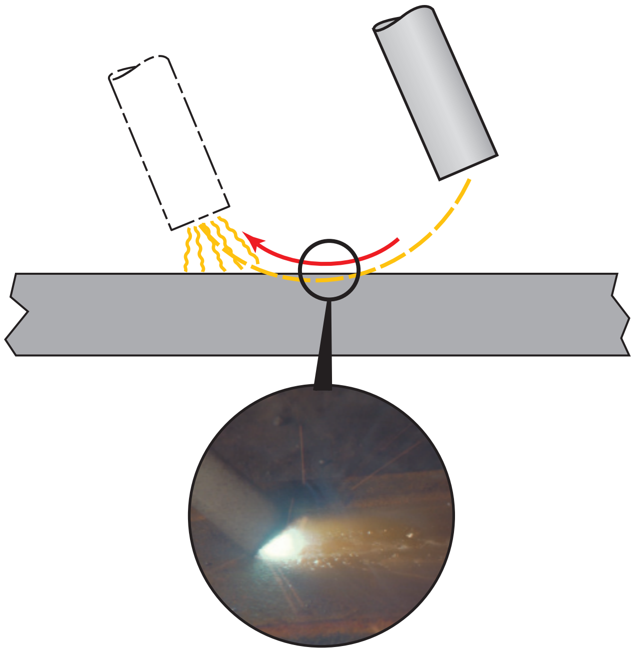


FIGURE 4-2 Striking the arc.

If the electrode sticks to the plate, quickly squeeze the electrode holder lever to release the electrode. Allow the electrode to briefly cool, and then break it free by bending it back and forth a few times. Do not touch the electrode without gloves because it will still be hot. Sometimes the flux will break away from the end of the electrode as the electrode is broken free from the plate. Restarting a partially used electrode is more difficult than restarting a new electrode, and restarting one with the flux broken off can be very difficult. While you are first beginning to make your practice welds, only use new electrodes or used electrodes that have the flux all the way to the electrode's end. Save the damaged electrodes so you can practice restarting them once you have developed your welding skills. With practice you should be able to strike these damaged electrodes as easily as you strike a new electrode, **Figure 4-3**.

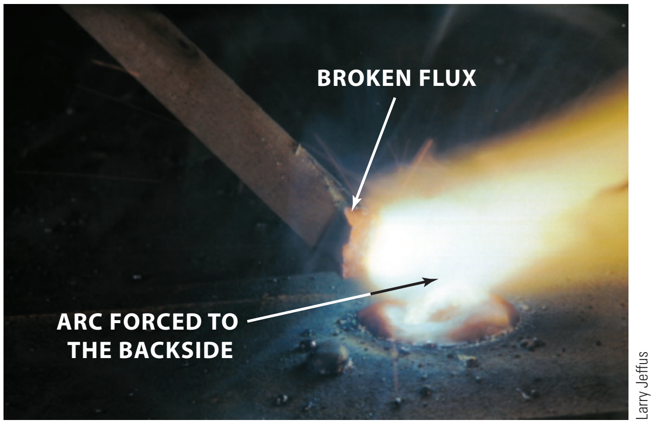


FIGURE 4-3 If the flux is broken off the end completely or on one side, then the arc can be erratic or forced to the side.

THINK GREEN

Use Scrap Metal

Most welding shops have a lot of scrap metal that can be used for experiments described in this chapter. Using scrap metal will not affect the experiment but will save material.

Once you are able to easily strike an arc and make a weld, try to strike the arc where it will be remelted by the weld you are making. Arc strikes on the metal's surface that are not covered up by the weld are considered to be weld defects by most codes.

Break the arc by rapidly raising the electrode back over the weld after completing a 1-in. (25-mm) -long weld bead. Breaking the arc back over the weld prevents arc marks in front of the weld and results in the arc ending back away from the leading edge of the weld bead. Both are good practices to start learning early in your welding career. Restart the arc as you did before and make another short weld. Repeat this process until you can easily start the arc each time. Turn off the welding machine and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 4-3

Striking the Arc Accurately

Using the same materials and setup as described in Practice 4-2, you will start the arc at a specific spot to prevent damage to the surrounding plate.

Hold the electrode over the desired starting point. After lowering your helmet, swiftly bounce the electrode against the plate, **Figure 4-4**. A lot of practice is required to develop the speed and skill needed to prevent the electrode from sticking to the plate.

A more accurate method of starting the arc involves holding the electrode steady by resting it on your free hand like a pool cue. The electrode is rapidly pushed forward so that it strikes the metal exactly where it should. This is an excellent method of striking an arc. Striking an arc in an incorrect spot may cause damage to the base metal.

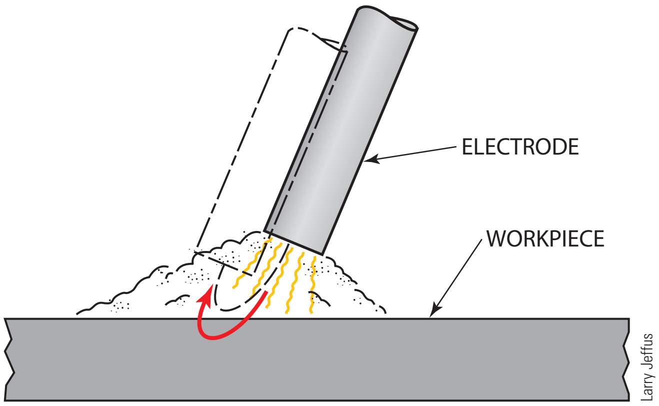


FIGURE 4-4 Striking the arc on a spot.

Practice starting the arc until you can start it within 1/4 in. (6 mm) of the desired location. If you are using an auto-darkening welding helmet, switch to a standard helmet or turn off the auto-darkening function and redo this experiment. Turn off the welding machine and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

EFFECT OF CURRENT SETTINGS THAT ARE TOO LOW OR TOO HIGH

Each welding electrode must be used in a specified current (amperage) range for it to operate correctly, **Table 4-1**. Quality welds cannot be made if the welding current setting is lower or higher than the manufacturer's range for any specific electrode type and diameter.

Too Low of a Current Setting

Welding with the current set too low results in poor fusion and poor arc stability, **Figure 4-5**. The weld may have slag or gas inclusions because the molten weld pool was not fluid long enough for the flux to react. Little or no penetration of the weld into the base plate may also be evident. With the current set too low, the arc length is very short. A very short arc length results in frequent shorting and sticking of the electrode.

Too High of a Current Setting

The core wire of the welding electrode is limited in the amount of current it can carry. As the current is increased, the wire heats up because of electrical resistance. This preheating of the wire causes some of the chemicals in the covering to be burned out too early, **Figure 4-6**. The loss of the proper balance of elements causes poor arc stability. This condition leads to spatter, porosity, and slag inclusions.

The weld bead made at a high amperage setting is wider and flatter with deeper penetration. Higher amperage settings can also result in an increase in the amount of spatter and it is mostly hard. The spatter is called hard because it fuses to the base plate and is difficult to remove, **Figure 4-7**. The electrode covering is discolored more than 1/8 in. (3 mm) to 1/4 in. (6 mm) from the end of the electrode. Extremely high settings may also cause the electrode to discolor, crack, glow red, or burn.

FIGURE 4-5 Welding with the amperage set too low.

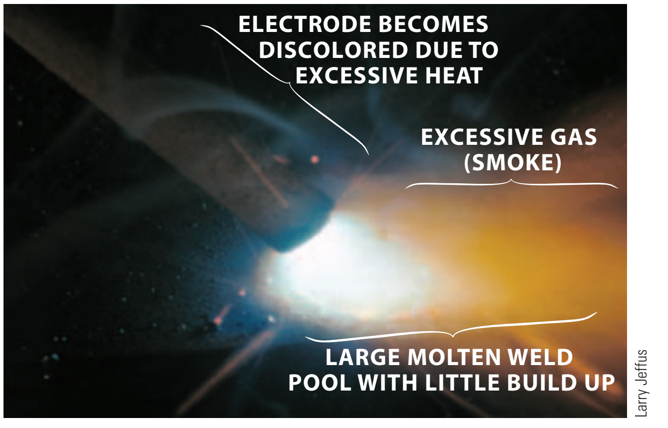


FIGURE 4-6 Welding with too high of an amperage.

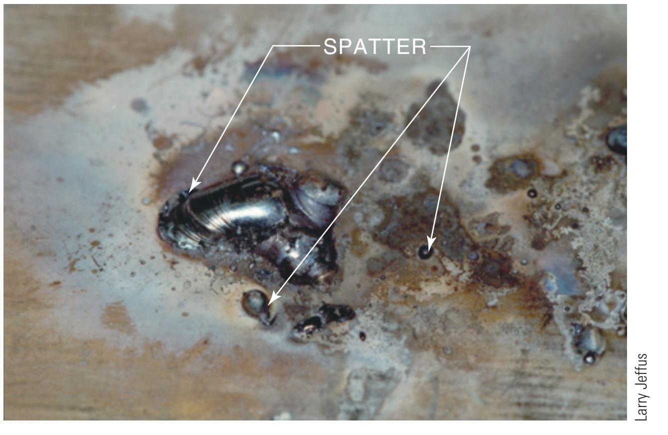


FIGURE 4-7 Hard weld spatter fused to base metal.

Electrode	Classification					
Size	E6010	E6011	E6012	E6013	E7016	E7018
3/32 in. (2.4 mm)	40-80	50-70	40-90	40-85	75-105	70-110
1/8 in. (3.2 mm)	70-130	85-125	75-130	70-120	100-150	90-165
5/32 in. (4 mm)	110-165	130-160	120-200	130-160	140-190	125-220

TABLE 4-1 Welding Amperage Range

EXPERIMENTS

The experiments in this chapter are designed to demonstrate the effects of welding outside of the normal welding parameters. They should be performed by a group of two or three other welding students. Take turns making the welds as the other students make adjustments to the welder setting and take notes. By working in a small group as a collaborative effort, better observations can be made. Discuss with the group your observations and compare them with the other group members. By performing all of the experiments you will be better able to troubleshoot welding problems that may occur in the field.

EXPERIMENT 4-1

Effect of Amperage Changes on a Weld Bead

For this experiment, you will need an arc welding machine, welding gloves, safety glasses, a welding helmet, appropriate clothing, E6011 welding electrodes with a 1/8-in. (3 mm) diameter, and one piece of mild steel plate 1/4 in. (6 mm) to 1/2 in. (13 mm) thick. You will observe what happens to the weld bead when the amperage settings are raised and lowered.

Starting with the machine set at approximately 90 A AC or DCRP, strike an arc and make a weld 1 in. (25 mm) long. Break the arc. Raise the current setting by 10 A, strike an arc, and make another weld 1 in. (25 mm) long. Repeat this procedure until the machine amperage is set at the maximum value.

Replace the electrode and reset the machine to 90 A. Make a weld 1 in. (25 mm) long. Stop and lower the current setting by 10 A. Repeat this procedure until the machine amperage is set at a minimum value.

Cool and chip the plate, comparing the different welds for width, buildup, molten weld pool size, spatter, slag removal, and penetration, **Figure 4-8A** and **B**. In addition, compare the electrode stubs. Turn off the welding machine and clean your work area when you are finished welding.

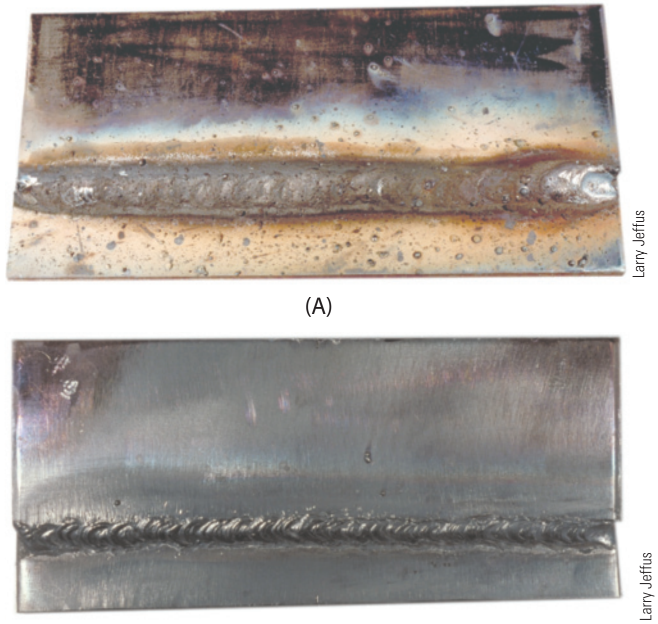
Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

CAUTION

Do not change the current settings during welding. A change in the setting may cause arcing inside the machine, resulting in damage to the machine.

ELECTRODE SIZE AND HEAT

The selection of the correct size of welding electrode for a weld is determined by some or all of the following: the skill of the welder, the thickness of the metal to be welded, the size of the metal, and welding codes or standards.



(A)

(B)

FIGURE 4-8 (A) Weld before cleaning. (B) Weld after cleaning.

Smaller diameter Using smaller diameter electrodes requires less skill than using large diameter electrodes because the molten weld pool is smaller and easier to control. Also, the deposition rate, or the rate that weld metal is added to the weld, is slower when small diameter electrodes are used. Small diameter electrodes will make acceptable welds on thick plate, but more time is required to make the weld.

Large diameter Larger diameter electrodes may overheat the metal if they are used with thin or small pieces of metal. To determine if a weld is too hot, watch the shape of the trailing edge of the molten weld pool, **Figure 4-9**. Rounded ripples indicate the weld is cooling uniformly and that the heat is not excessive. If the ripples are pointed, then the weld is cooling too slowly because of excessive heat. Extreme overheating can cause a burnthrough. Once a burnthrough occurs, it is hard to repair.

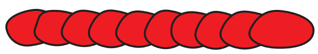
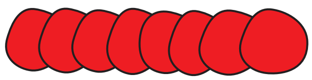
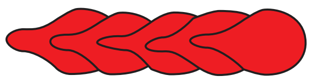
AMOUNT OF HEAT DIRECTED AT WELD	WELD POOL
TOO LOW	
CORRECT	
TOO HOT	

FIGURE 4-9 The effect on the shape of the molten weld pool caused by the heat input.

Overheating problems Overheating problems can be corrected by turning down the amperage, using a shorter arc, traveling at a faster rate, using a **chill plate** (a large piece of metal used to absorb excessive heat), or using a smaller electrode at a lower current setting.

EXPERIMENT 4-2

Excessive Heat

Using a properly set up and adjusted arc welding machine, the proper safety protection, E6011 welding electrodes with a 1/8 in. (3 mm) diameter, and three pieces of mild steel plate with thicknesses of 1/8 in. (3 mm), 3/16 in. (4.8 mm), and 1/4 in. (6 mm) thick, you will observe the effects of overheating on the weld. Make a stringer weld on each of the three plates using the same amperage setting, travel rate, and arc length for each weld. Cool and chip the welds. Then, compare the weld beads for width, reinforcement, and appearance.

Using the same amperage settings, make additional welds on the 1/8-in. (3-mm) and 3/16-in. (4.8-mm) plates. Vary the arc lengths and travel speeds for these welds. Cool and chip each weld and compare the beads for width, reinforcement, and appearance. Make additional welds on the 1/8-in. (3-mm) and 3/16-in. (4.8-mm) plates using the same arc length and travel speed as in the earlier part of this experiment but at a lower amperage setting. Cool and chip the welds and compare the beads for width, reinforcement, and appearance.

Welders often use the terms ***heat*** and ***amperage*** interchangeably when they are speaking about making changes to the welding current. For example, welders may say "Turn up the heat a little" or "Turn up the amperage a little." In both cases, they are asking for the welding amperage to be increased a little.

The plates should be cooled between each weld so that the heat from the previous weld does not affect the test results. Turn off the welding machine and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

ARC LENGTH

The **arc length** is the distance the arc must jump from the end of the electrode to the plate or weld pool surface. As the weld progresses, the electrode becomes shorter as it is consumed. To maintain a constant arc length, the electrode must be lowered continuously. Maintaining a constant arc length is important, because too great a change in the arc length will adversely affect the weld.

Shorter arc lengths Shorter arc lengths may cause the metal transferring across the gap to short out the electrode, causing it to stick to the plate. The weld that results from a short arc is narrow and has a high buildup, **Figure 4-10**.

Long arc lengths Long arc lengths produce more spatter because the metal being transferred may drop outside of the molten weld pool. The weld is wider and has little buildup, **Figure 4-11**.

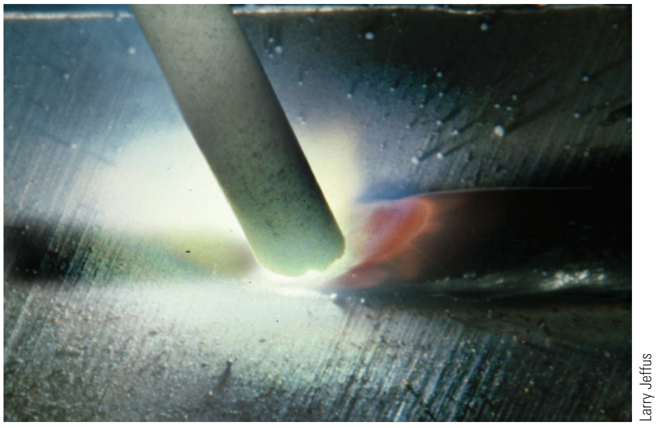


FIGURE 4-10 Welding with too short of an arc length.

FIGURE 4-11 Welding with too long of an arc length.

There is a narrow range for the arc length in which it is stable, metal transfer is smooth, spatter is minimized, and the bead shape is controlled. Factors affecting the length are the type of electrode, joint design, metal thickness, and current setting.

Some welding electrodes, such as E7024, have a thick flux covering. The rate at which the covering melts is slow enough to permit the electrode coating to be rested against the plate. The arc burns back inside the covering as the electrode is dragged along touching the joint, **Figure 4-12**. For that reason electrodes like E7024 are sometimes referred to as drag electrodes or drag rods. For this type of welding

FIGURE 4-12 Welding with a drag technique.

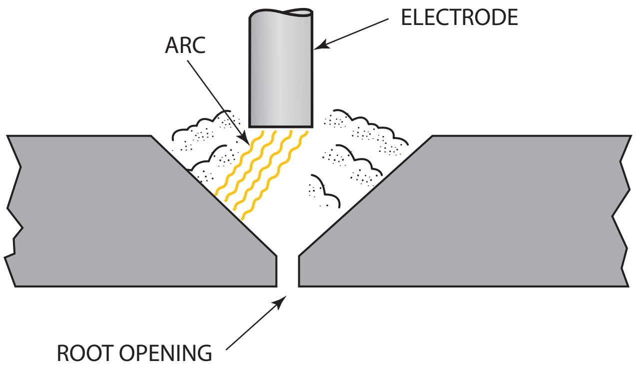


FIGURE 4-13 The arc may jump to the closest metal, reducing root penetration.

electrode, the arc length is maintained by the electrode covering.

An arc will jump to the closest metal conductor. On joints that are deep or narrow, the arc is pulled to one side and not to the root, **Figure 4-13**. As a result, the root fusion is reduced or may be nonexistent, thus causing a poor weld. If a very short arc is used, then the arc is forced into the root for better fusion.

Because shorter arcs produce less heat and penetration, they are best suited for use on thin metal or thin-to-thick metal joints. Using this technique, metal as thin as 16 gauge can be arc welded easily. Higher amperage settings are required to maintain a short arc that gives good fusion with a minimum of slag inclusions. The higher settings, however, must be within the **amperage range** for the specific electrode.

Finding the correct arc length often requires some trial and adjustment. Most welding jobs require an arc length of 1/8 in. (3 mm) to 3/8 in. (10 mm) when using a 1/8 in. (3 mm) electrode, but this distance varies. It may be necessary to change the arc length when welding to adjust for varying welding conditions.

EXPERIMENT 4-3

Effect of Changing the Arc Length on a Weld

Using an arc welding machine, welding gloves, safety glasses, welding helmet, appropriate clothing, E6011 welding electrodes with a 1/8 in. (3 mm) diameter, and one piece of mild steel plate 1/4 in. (6 mm) to 1/2 in. (13 mm) thick, you will observe the effect of changing the arc length on a weld.

Starting with the welding machine set at approximately 90 A AC or DCRP, strike an arc and make a weld 1 in. (25 mm) long. Continue welding while slowly increasing the arc length until the arc is broken. Restart the arc and make another weld 1 in. (25 mm) long. Welding should again be continued while slowly shortening the arc length until the arc stops. Quickly break the electrode free from the plate or release the electrode by squeezing the lever on the electrode holder.

Cool and chip both welds. Compare both welding beads for width, reinforcement, uniformity, spatter, and appearance. Turn off the welding machine and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

TRAVEL ANGLE, ELECTRODE ANGLE AND WORK ANGLE

The terms **travel angle** and **electrode angle** both refer to the relationship between the angle of the electrode as it relates to the direction of weld travel, **Figure 4-14A**. The term **work angle** refers to the relationship between the center of the electrode and the surface of the work, **Figure 4-14B**. The relative angle is important because there is a jetting force blowing the metal and flux from the end of the electrode to the plate.

Leading Angle

A leading electrode angle pushes molten metal and slag ahead of the weld, **Figure 4-15**. When welding in the flat position, caution must be taken to prevent cold lap and slag inclusions. The solid metal ahead of the weld cools and solidifies the molten filler metal and slag before they can melt the solid metal. This rapid cooling prevents the metals from fusing together, **Figure 4-16**. As the weld passes over this area, heat from the arc may not melt it. As a result, some cold lap and slag inclusions are left.

The following are suggestions for preventing cold lap and slag inclusions:

- Use as little leading angle as possible.
- Ensure that the arc melts the base metal completely, **Figure 4-17**.

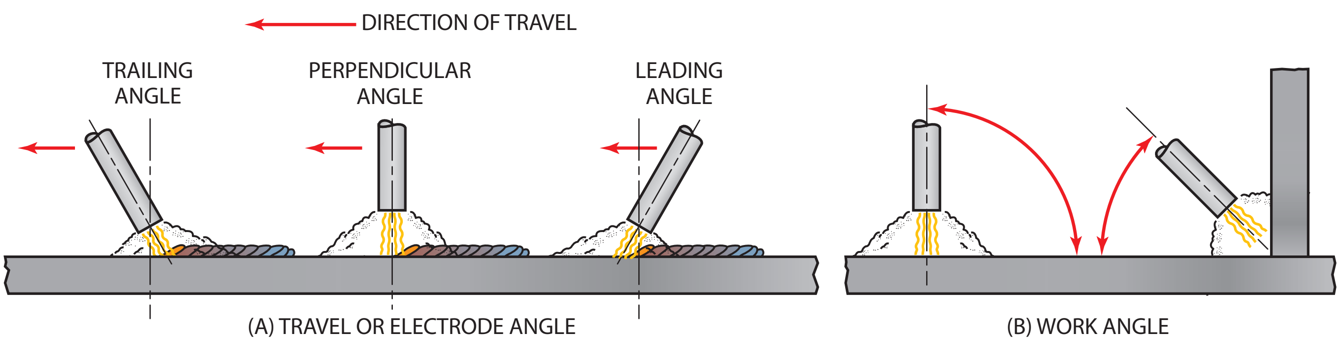


FIGURE 4-14 Direction of travel and electrode angle.

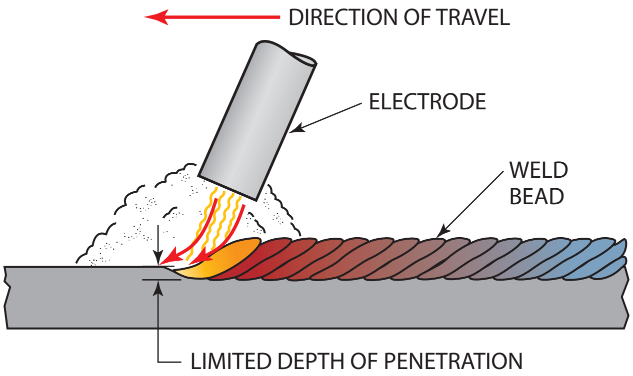


FIGURE 4-15 Leading, lag, or pushing electrode angle.

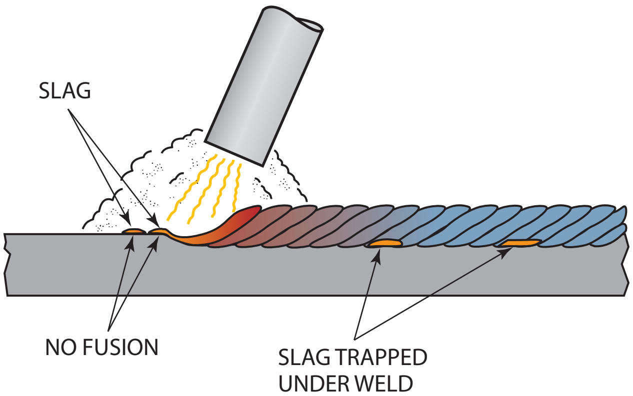


FIGURE 4-16 Some electrodes, such as E7018, may not remove the deposits ahead of the molten weld pool, resulting in discontinuities within the weld.

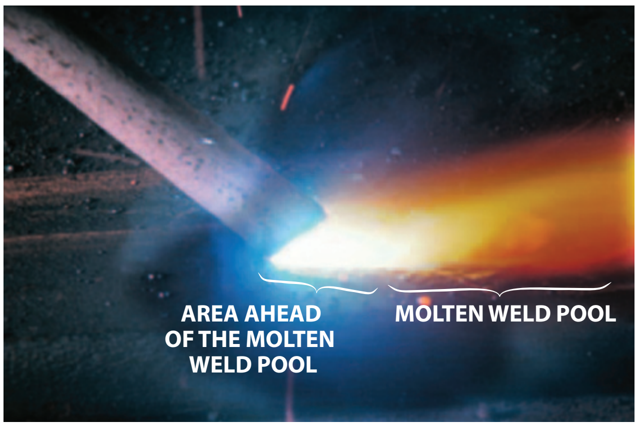


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FIGURE 4-17 Metal being melted ahead of the molten weld pool helps to ensure good weld fusion.

- Use a penetrating-type electrode that causes little buildup.
- Move the arc back and forth across the molten weld pool to fuse both edges.

A leading angle can be used to minimize penetration or to help hold molten metal in place for vertical welds, **Figure 4-18**.

Perpendicular Angle

A perpendicular angle directs all of the electrodes jetting force directly into the joint. It provides a balanced weld bead shape between the leading angle weld and the trailing angle weld.

Trailing Angle

A trailing electrode angle pushes the molten metal away from the leading edge of the molten weld pool toward the back where it solidifies, **Figure 4-19**. As the molten metal is forced away from the bottom of the weld, the arc melts more of the base metal, which results in deeper penetration. The molten metal pushed to the back of the weld solidifies and forms reinforcement for the weld, **Figure 4-20**.

EXPERIMENT 4-4

Effect of Changing the Electrode Angle on a Weld

Using a properly set up and adjusted arc welding machine, the proper safety protection, E6011 welding electrodes with a 1/8 in. (3 mm) diameter, and one piece of mild steel plate 1/4 in. (6 mm) to 1/2 in. (13 mm) thick, you will observe the effect of changes in the electrode angle on a weld.

Start welding with a sharp trailing angle. Make a weld approximately 1 in. (25 mm) long. Closely observe the molten weld pool at the points shown in **Figure 4-21**. Slowly increase the electrode angle and continue to observe the weld.

When you reach a 90° electrode angle, make a weld approximately 1 in. (25 mm) long. Observe the parts of the molten weld pool as shown in Figure 4-21.

Continue welding and change the electrode angle to a sharp leading angle. Observe the molten weld pool at the points shown in **Figure 4-22**.

During this experiment, you must maintain a constant arc length, travel speed, and weave pattern if the observations and results are to be accurate.

Cool and chip the weld. Compare the weld bead for uniformity in width, reinforcement, and appearance. Turn off the welding machine and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

ELECTRODE MANIPULATION

The movement or weaving of the welding electrode can control the following characteristics of the weld bead: penetration, buildup, width, porosity, undercut, overlap, and slag inclusions. The exact **weave pattern** for each weld is often the personal choice of the welder. However, some patterns are especially helpful for specific welding situations. The pattern selected for a flat (1G) butt joint is not as critical as the pattern selection for other joints and other positions.

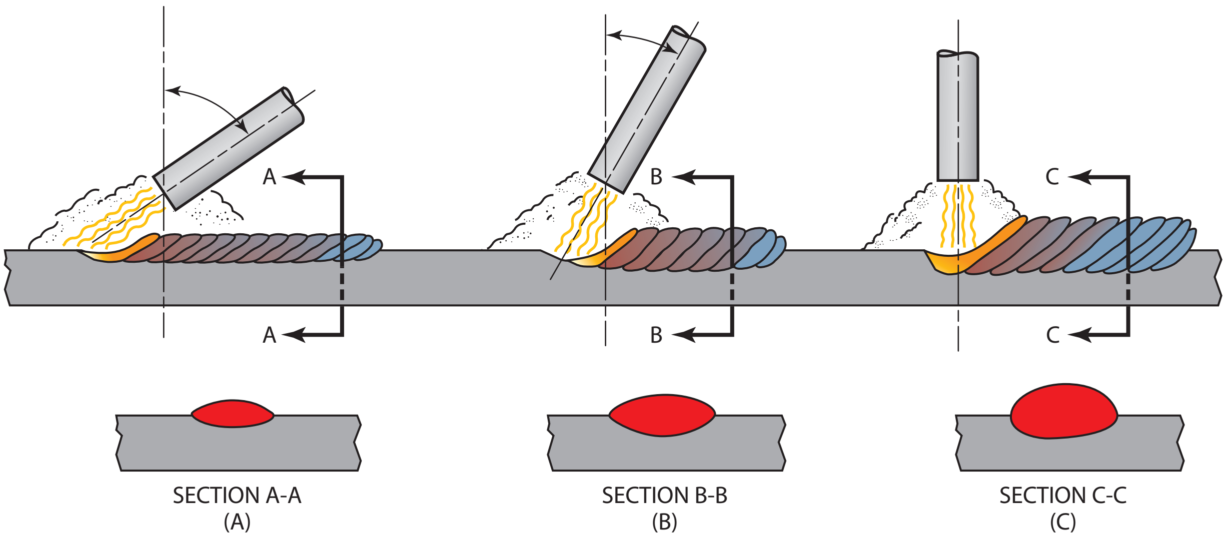

FIGURE 4-18 (A) Effect of a leading angle on weld bead buildup, width, and penetration. (B) As the angle increases toward the vertical position, (C) penetration increases.

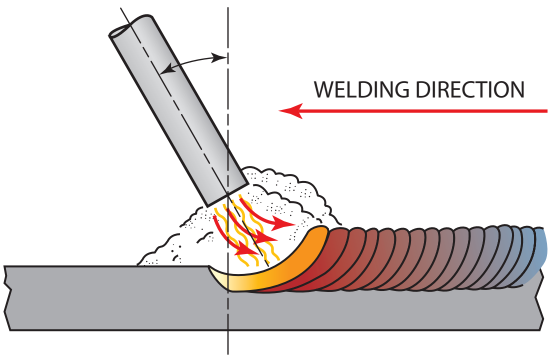

FIGURE 4-19 Trailing electrode angle.

Many weave patterns are available for the welder to use. **Figure 4-23** shows 10 different patterns that can be used for most welding conditions.

Circular patterns Circular patterns are often used for flat position welds on butt, tee, and outside corner joints, and for buildup or surfacing applications. The circle can be made wider or longer to change the bead width or penetration, **Figure 4-24**.

"C" and square patterns "C" and square patterns are both good for most 1G (flat) welds but can also be used for vertical (3G) positions. These patterns can also be used if there is a large gap to be filled when both pieces of metal are nearly the same size and thickness.

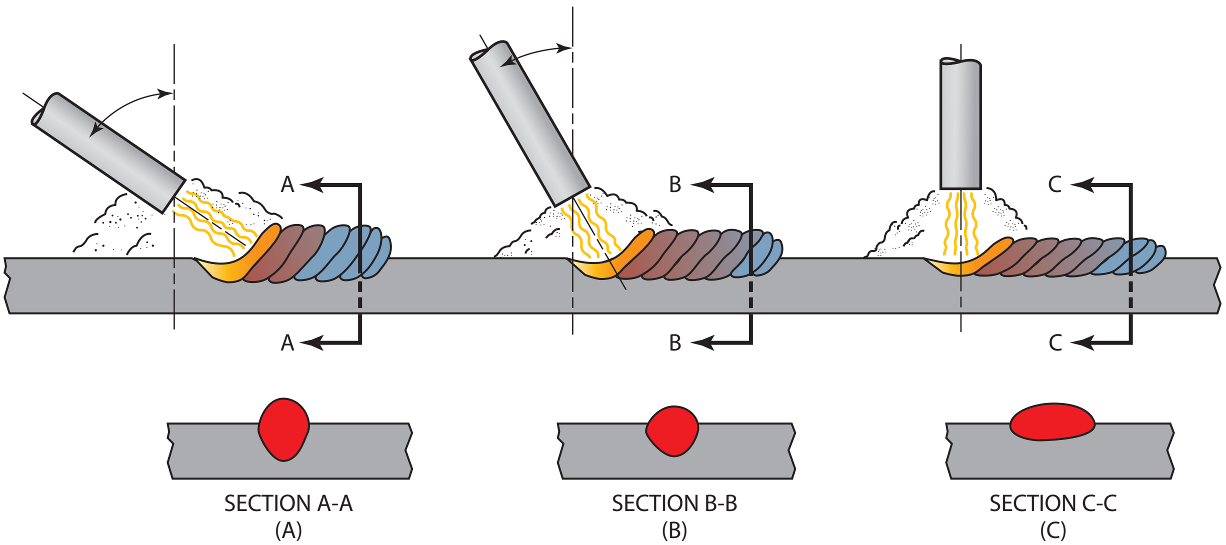

FIGURE 4-20 (A) Effect of a trailing angle on weld bead buildup, width, and penetration. (B) As the angle changes toward the vertical position, (C) the penetration decreases and the weld width increases.

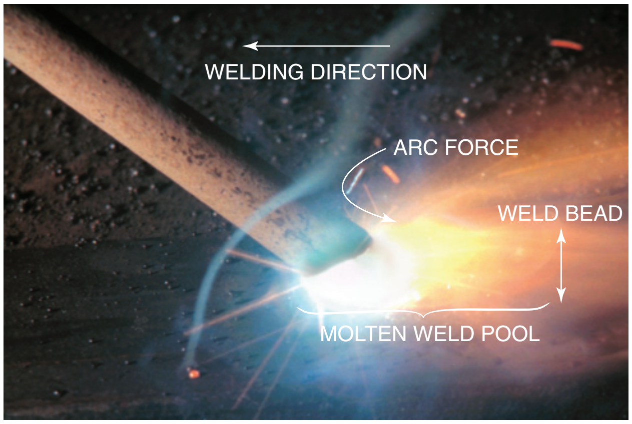

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FIGURE 4-21 Welding with a trailing angle.

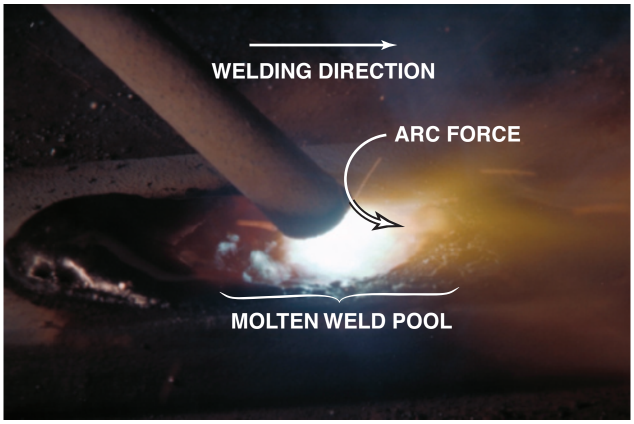

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FIGURE 4-22 Welding with a leading angle.

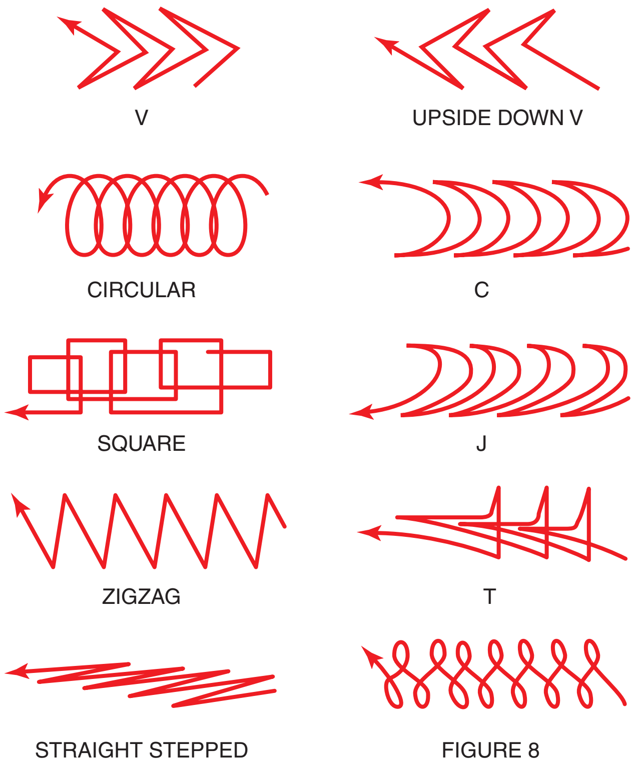


FIGURE 4-23 Weave patterns.

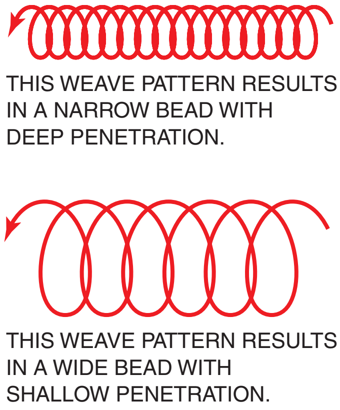


FIGURE 4-24 Changing the weave pattern width to change the weld bead characteristics.

"J" patterns "J" patterns work well on flat (1F) lap joints, all vertical (3G) joints, and horizontal (2G) butt and lap (2F) welds. This pattern allows the heat to be concentrated on the thicker plate, **Figure 4-25**. It also allows the reinforcement to be built up on the metal deposited during the first part of the pattern. As a result, a uniform bead contour is maintained during out-of-position welds.

"T" patterns "T" patterns work well with fillet welds in the vertical (3F) and overhead (4F) positions, **Figure 4-26**. It also can be used for deep groove welds for the hot pass. The top of the "T" can be used to fill in the toe of the weld to prevent undercutting.

Straight step patterns Straight step patterns can be used for stringer beads, root pass welds, and multiple pass welds in all positions. For this pattern, the smallest

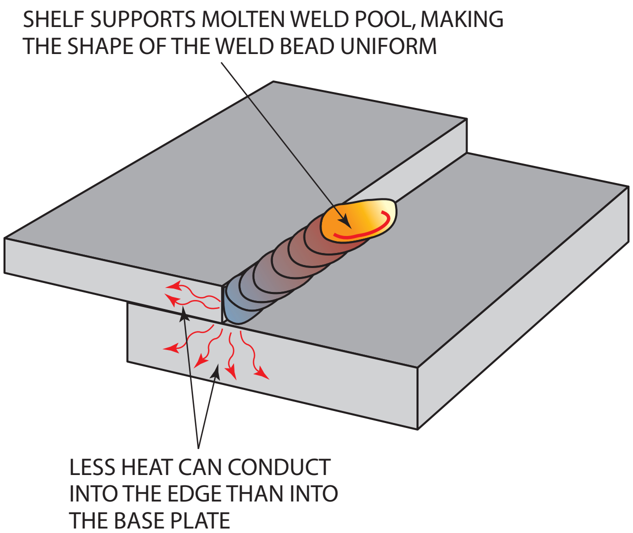


FIGURE 4-25 The "J" pattern allows the heat to be concentrated on the thicker plate.

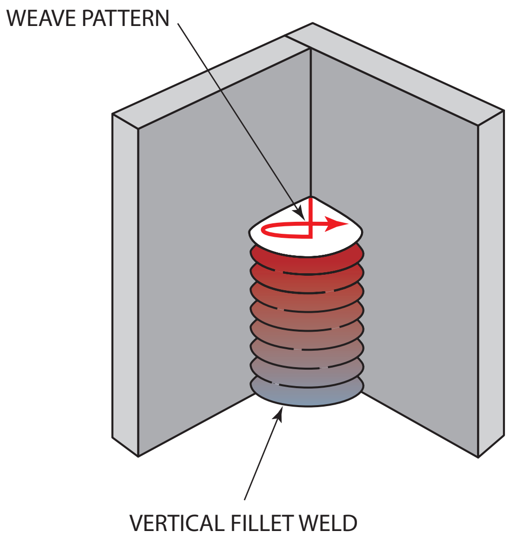


FIGURE 4-26 "T" pattern.

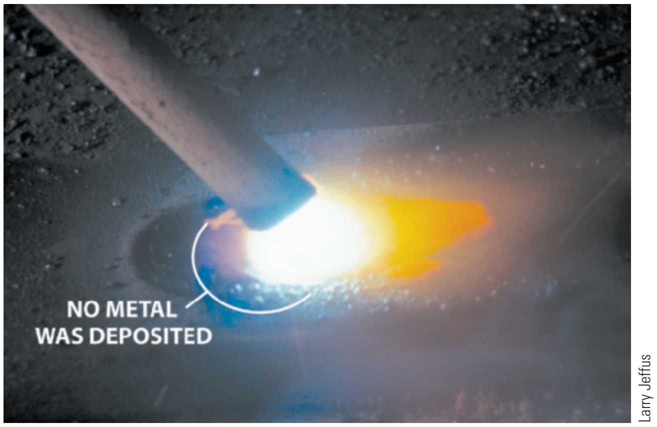


FIGURE 4-28 The electrode does not deposit metal or melt the base metal.

quantity of metal is molten at one time as compared to other patterns. Therefore, the weld is more easily controlled. At the same time that the electrode is stepped forward, the arc length is increased so that no metal is deposited ahead of the molten weld pool, **Figure 4-27** and **Figure 4-28**. This action allows the molten weld pool to cool to a controllable size. In addition, the arc burns off any paint, oil, or dirt from the metal before it can contaminate the weld.

-8 and zigzag patterns -8 and zigzag patterns are used as cover passes in the flat and vertical positions. Do not weave more than 2 1/2 times the width of the electrode. These patterns deposit a large quantity of metal at one time. A shelf can be used to support the molten weld pool when making vertical welds using either of these patterns, **Figure 4-29**.

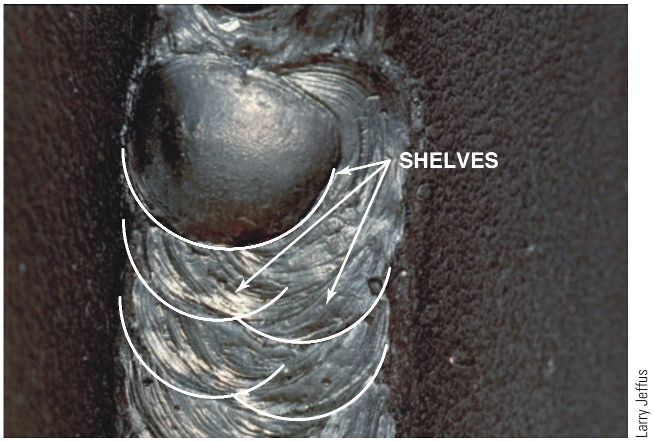


FIGURE 4-29 Using the shelf to support the molten pool for vertical welds.

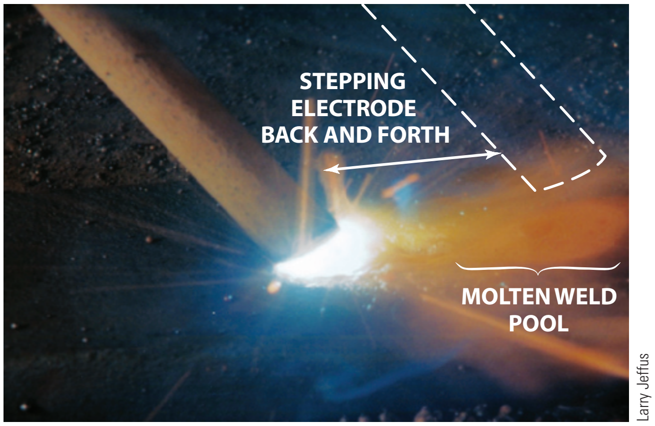


FIGURE 4-27 The electrode is moved slightly forward and then returned to the weld pool.

POSITIONING OF THE WELDER AND THE PLATE

The welder should be in a relaxed, comfortable position before starting to weld. A good position is important for both the comfort of the welder and the quality of the welds. Welding in an awkward position can cause welder fatigue, which leads to poor welder coordination and poor-quality welds. Welders must have enough freedom of movement so that they do not need to change position during a weld. Body position changes should be made only during electrode changes.

When the welding helmet is down, the welder is blind to the surroundings. Due to the arc, the field of vision of the welder is also very limited. These factors often cause the welder to sway. To stop this swaying, the welder should lean against or hold onto a stable object. When welding, even if a welder is seated, touching a stable object will make that welder more stable and will make welding more relaxing.

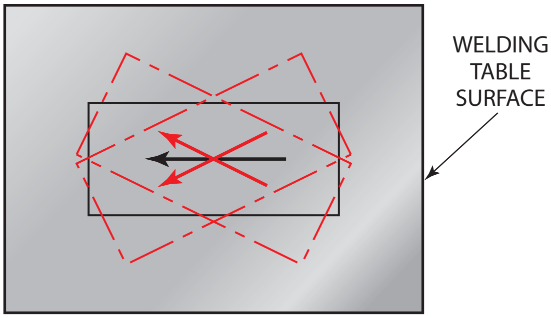


FIGURE 4-30 Change the plate angle to find the most comfortable welding position.

Welding is easier if the welder can find the most comfortable angle. The welder should be in either a seated or a standing position in front of the welding table. The welding machine should be turned off. With an electrode in place in the electrode holder, the welder can draw a straight line along the plate to be welded. By turning the plate to several different angles, the welder should be able to determine which angle is most comfortable for welding, **Figure 4-30**.

PRACTICE WELDS

Practice welds are grouped according to the type of joint and the type of welding electrode. The welder or instructor should select the order in which the welds are made. The stringer beads should be practiced first in each position before the welder tries the different joints in each position. Some time can be saved by starting with the stringer beads. If this is done, then it is not necessary to cut or tack the plate together, and a number of beads can be made on the same plate.

THINK GREEN

Use Both Sides of the Plate

Making welds on both sides of the weld plates will double the amount of practice welds that can be made on a single piece of practice plate.

Students will find it easier to start with butt joints. The lap, tee, and outside corner joints are all approximately the same level of difficulty.

Starting with the flat position allows the welder to build skills slowly so that out-of-position welds become easier to do. The horizontal tee and lap welds are almost as easy to make as the flat welds. Overhead welds are as simple to make as vertical welds, but they are harder to position. Horizontal butt welds are more difficult to perform than most other welds.

ELECTRODES

Arc welding electrodes used for practice welds are grouped into three filler metal (F number) classes according to their major welding characteristics. The groups are E6010 and E6011, E6012 and E6013, and E7016 and E7018.

F3 E6010 and E6011 Electrodes

Both of these electrodes have **cellulose-based fluxes**. As a result, these electrodes have a forceful arc with little slag left on the weld bead.

F2 E6012 and E6013 Electrodes

These electrodes have **rutile-based fluxes**, giving a smooth, easy arc with a thick slag left on the weld bead.

F4 E7016 and E7018 Electrodes

Both of these electrodes have a **mineral-based flux**. The resulting arc is smooth and easy, with a very heavy slag left on the weld bead.

Electrode Selection

Often electrode specifications are made in a Welding Procedure Specification (WPS) for the welds to be made on a weldment. Without a WPS, the welder has the final choice. An accomplished welder can make defect-free welds on all types of joints using all types of electrodes in any weld position. More information on electrode selection can be found in Chapter 27.

Cellulose-based flux Cellulose-based flux electrodes produce welds that have a thin slag covering the molten weld pool giving the welder a clearer view of the weld. The thinner slag covering and a forceful arc make it easier to have full root fusion and to make welds in vertical, horizontal, and overhead positions. These electrodes produce a larger quantity of welding fumes and sparks than the other two groups of electrodes used in these practices.

Rutile-based flux Rutile-based flux electrodes have a softer arc, smoother arc, and produce less welding fumes and sparks than cellulose-based electrodes. These electrode's molten weld pools have a slightly heavier slag covering that can slightly obstruct the welder's view. Slag can sometimes buildup in the joint in front of the weld pool, which can prevent complete root fusion. The finished weld will have a heaver slag covering, too.

The cellulose-based and rutile-based groups of electrodes have welding characteristics that make them the best electrode choices for beginning welders.

Mineral-based flux Mineral-based flux electrodes produce welds with the heaviest slag covering both the molten weld pool and finished weld bead, which makes it more difficult to see the molten weld pool. It is sometimes especially hard for new welders to see the trailing edge of the weld pool. Care must be taken to insure complete root fusion on groove and fillet welds. It is important to keep these electrodes dry and free from contamination. Porosity can often form in the weld as it is being started while the arc is beginning to stabilize. **Figure 4-31** shows a starting

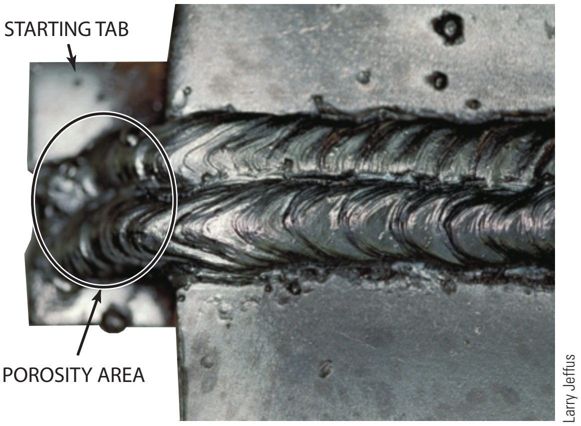


FIGURE 4-31 Porosity is found on the starting tab where it will not affect the weld.

FIGURE 4-33 New welders frequently see only the arc and sparks from the electrode.

tab used to prevent startup porosity from becoming part of the finished weld.

STRINGER BEADS

A straight weld bead on the surface of a plate, with little or no side-to-side electrode movement, is known as a **stringer bead**. Stringer beads are used by students to practice maintaining arc length and electrode angle so that their welds will be straight, uniform, and free from defects. Stringer beads, **Figure 4-32**, are also used to set the machine amperage and for buildup or surfacing applications. Stringer beads are the most commonly used type of bead for vertical, horizontal, and overhead welds.

The stringer bead should be straight. A beginning welder needs time to develop the skill of viewing the entire welding area. At first, the welder sees only the arc, **Figure 4-33**. With practice, the welder begins to see parts of the molten weld pool. After much practice, the welder will see the molten weld pool (front, back, and both sides), slag, buildup, and the surrounding plate, **Figure 4-34**. Often, at this skill level, the welder may not even notice the arc.

A straight weld is easily made once the welder develops the ability to view the entire welding zone. The welder will occasionally glance around to ensure that the weld is straight. In addition, it can be noted if the weld is uniform and free from defects. The ability of the welder to view the entire weld area is demonstrated by making consistently straight and uniform stringer beads.

After making practice stringer beads, a variety of weave bead patterns should be practiced to gain the ability to control the molten weld pool when welding out of position.

FIGURE 4-32 Stringer bead.

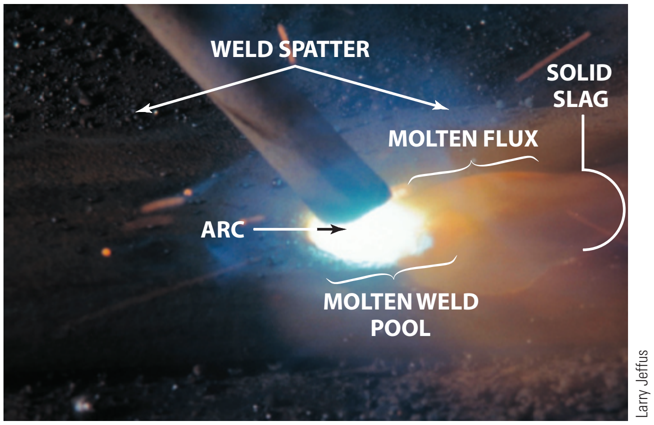


FIGURE 4-34 More experienced welders can see the molten pool, metal being transferred across the arc, and penetration into the base metal.

PRACTICE 4-4

Straight Stringer Beads in the Flat Position Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes

Using a properly set up and adjusted arc welding machine, proper safety protection, as demonstrated in Practice 4-1, arc welding electrodes with a 1/8 in. (3 mm) diameter, and one piece of mild steel plate 6 in. (152 mm) long and 1/4 in. (6 mm) thick, you will make straight stringer beads.

- Starting at one end of the plate, make a straight weld the full length of the plate.

- Watch the molten weld pool at this point, not the end of the electrode. As you become more skillful, it is easier to watch the molten weld pool.
- Repeat the beads with all three (F) groups of electrodes until you have consistently good beads.
- Cool, chip, and inspect the bead for defects after completing it. Turn off the welding machine and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 4-5

Stringer Beads in the Vertical Up Position Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes

Using the same setup, materials, and electrodes as listed in Practice 4-4, you will make vertical up stringer beads. Start with the plate at a 45° angle.

This technique is the same as that used to make a vertical weld. However, a lower level of skill is required at 45°, and it is easier to develop your skill. After the welder masters the 45° angle, the angle is increased successively until a vertical position is reached, **Figure 4-35**.

Before the molten metal drips down the bead, the back of the molten weld pool will start to bulge, **Figure 4-36**. When this happens, increase the speed of travel and the weave pattern.

Cool, chip, and inspect each completed weld for defects. Repeat the beads as necessary with all three (F) groups of electrodes until consistently good beads are obtained in this position. Turn off the welding machine and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

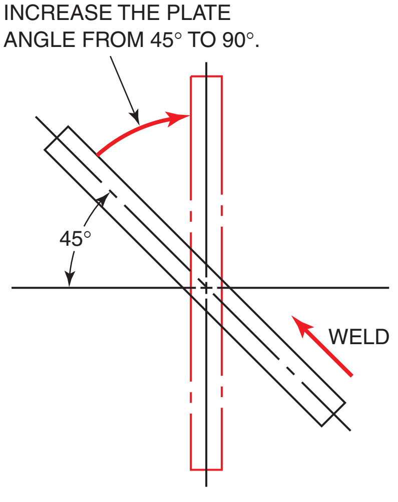


FIGURE 4-35 Once the 45° angle is mastered, the plate angle is increased successively until a vertical position (90°) is reached.

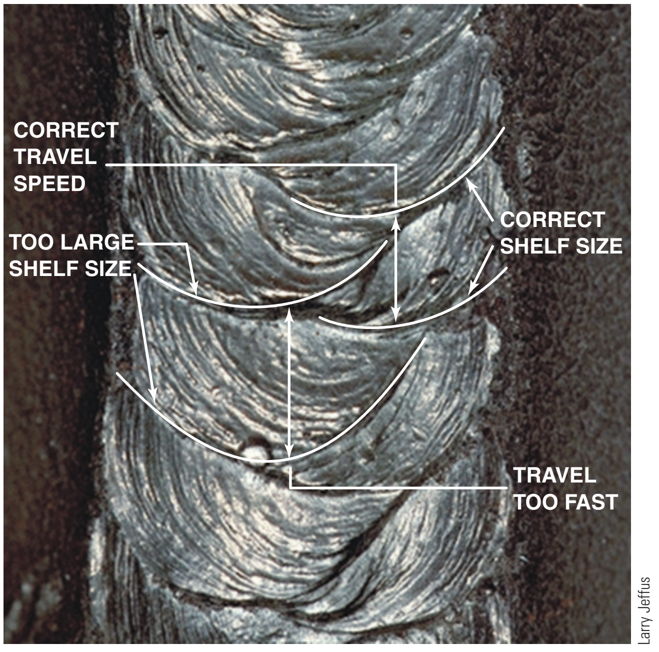


FIGURE 4-36 E7018 vertical up-weld.

PRACTICE 4-6

Horizontal Stringer Beads Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes

Using the same setup, materials, and electrodes as listed in Practice 4-4, you will make horizontal stringer beads on a plate.

When the welder begins to practice the horizontal stringer bead, the plate may be reclined slightly, **Figure 4-37**. This placement allows the welder to build the required skill by practicing the correct techniques successfully. The "J" weave pattern is suggested for this practice. As the electrode is drawn along the straight back of the "J," metal is deposited. This metal supports the molten weld pool, resulting in a bead with a uniform contour, **Figure 4-38**.

Angling the electrode up and back toward the weld causes more metal to be deposited along the top edge of the weld. Keeping the bead small allows the surface tension to hold the molten weld pool in place.

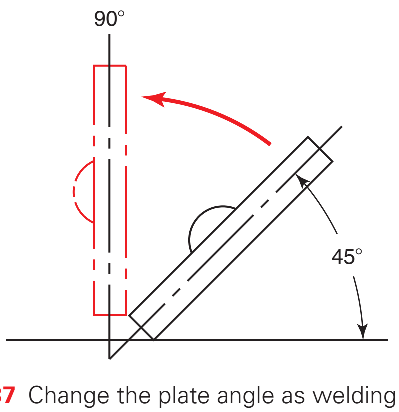


FIGURE 4-37 Change the plate angle as welding skill improves.

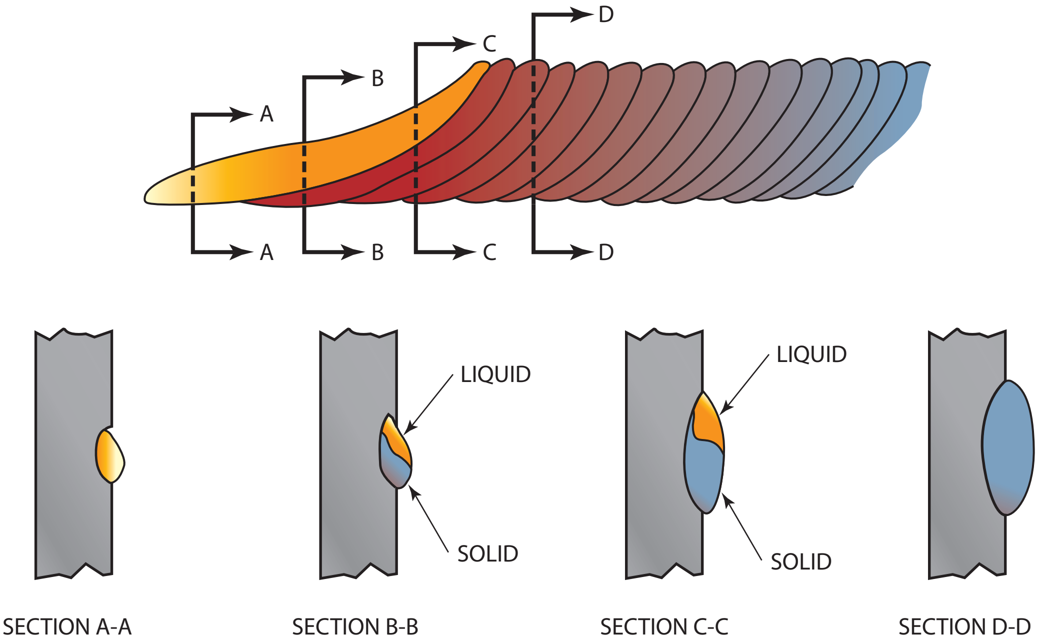


FIGURE 4-38 (A) Along the leading edge, a small molten weld pool is held in place by surface tension. (B) Farther back along the weld, the lower edge begins to solidify holding the small molten weld in place along the top edge. This process continues through (C) forming a uniformly shaped solid weld (D).

Gradually increase the angle of the plate until it is vertical and the stringer bead is horizontal. Repeat the beads as needed with all three (F) groups of electrodes until consistently good beads are obtained in this position. Turn off the welding machine and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

SQUARE BUTT JOINT

The **square butt joint** is made by tack welding two flat pieces of plate together, **Figure 4-39**. The tack weld must be small, uniform, and free of defects so it does not adversely affect the finished weld. The space between the plates is called the root opening or root gap. Changes in the root opening will affect penetration. As the space increases, the weld penetration also increases. The root opening for most butt welds will vary from 0 in. (0 mm) to 1/8 in. (3 mm). Excessively large openings can cause burnthrough or a cold lap at the weld root, **Figure 4-40**.

FIGURE 4-39 The tack weld should be small and uniform to minimize its effect on the final weld.

After a butt weld is completed, the plate can be cut apart so it can be used for rewelding. The strips for butt welding should be no smaller than 1 in. (25 mm) wide. If they are too narrow, then there will be a problem with heat buildup.

If the plate strips are no longer flat after the weld has been cut out, then they can be tack welded together and flattened with a hammer, **Figure 4-41**.

THINK GREEN

Reuse Practice Plates

The 1-in. (25-mm) -wide strips welded together for the practices can be cut through the clean metal between the welds. This will give you two clean edges so you can make additional practice welds on the same material, **Figure 4-42**. The same method of reusing practice plates can be applied to the other joints, too.

PRACTICE 4-7

Welded Square Butt Joint in the Flat Position (1G) Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes

Using a properly set up and adjusted arc welding machine, proper safety protection, arc welding electrodes with a 1/8 in.

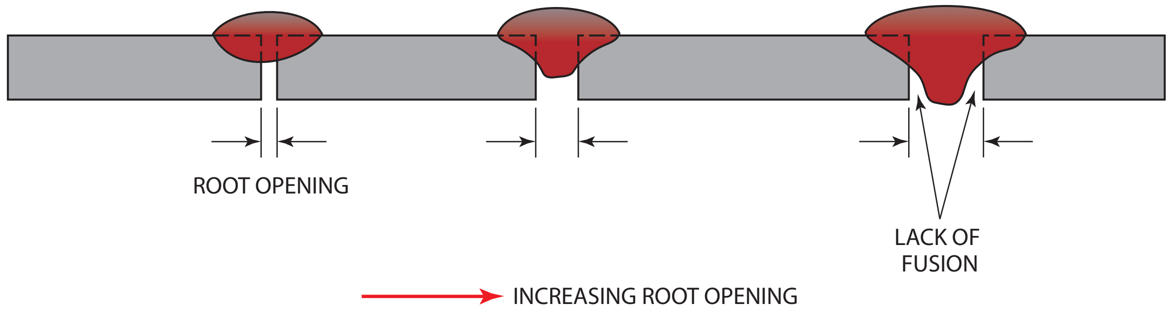


FIGURE 4-40 Effect of root opening on weld penetration.

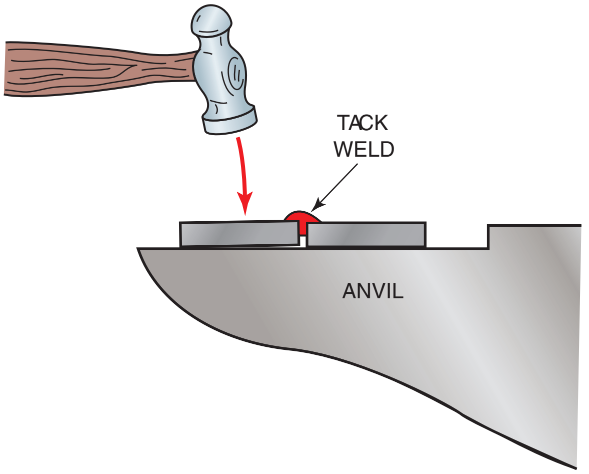


FIGURE 4-41 After the plates are tack welded together, they can be forced into alignment by striking them with a hammer.

(3 mm) diameter, and two or more pieces of mild steel plate 6 in. (152 mm) long and 1/4 in. (6 mm) thick, you will make a welded square butt joint in the flat position, **Figure 4-43**.

Tack weld the plates together and place them flat on the welding table. Starting at one end, establish a molten weld pool on both plates. Hold the electrode in the molten weld pool until it flows together, **Figure 4-44**. After the gap is bridged by the molten weld pool, start weaving the electrode slowly back and forth across the joint. Moving the electrode too quickly from side to side may result in slag being trapped in the joint, **Figure 4-45**.

Continue the weld along the 6-in. (152-mm) length of the joint. Normally, deep penetration is not required for this type of weld. If full plate penetration is required, then the edges of the butt joint should be beveled or a larger-than-normal root gap should be used. Cool, chip, and inspect the weld for uniformity and soundness. Repeat the welds as needed to master all three (F) groups of electrodes in this position. Turn off the welding machine and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 4-8

Vertical (3G) Up-Welded Square Butt Weld Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes

Using the same setup, materials, and electrodes as listed in Practice 4-7, you will make vertical up-welded square butt joints.

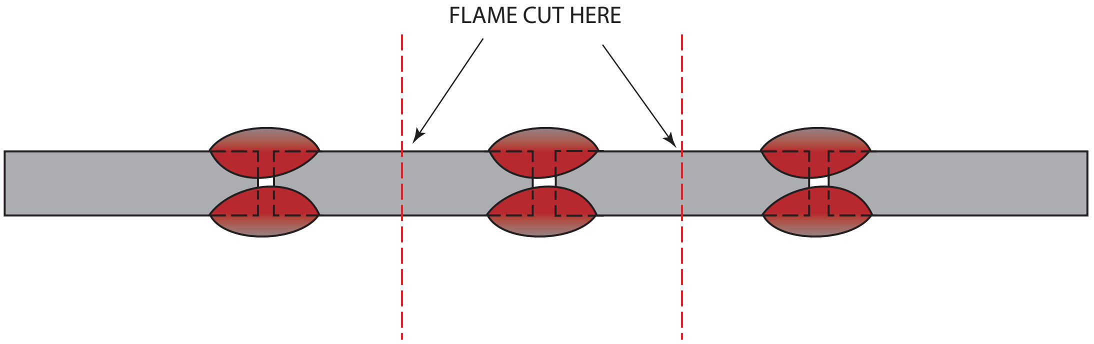


FIGURE 4-42 Conserve material and reuse practice plates when possible.

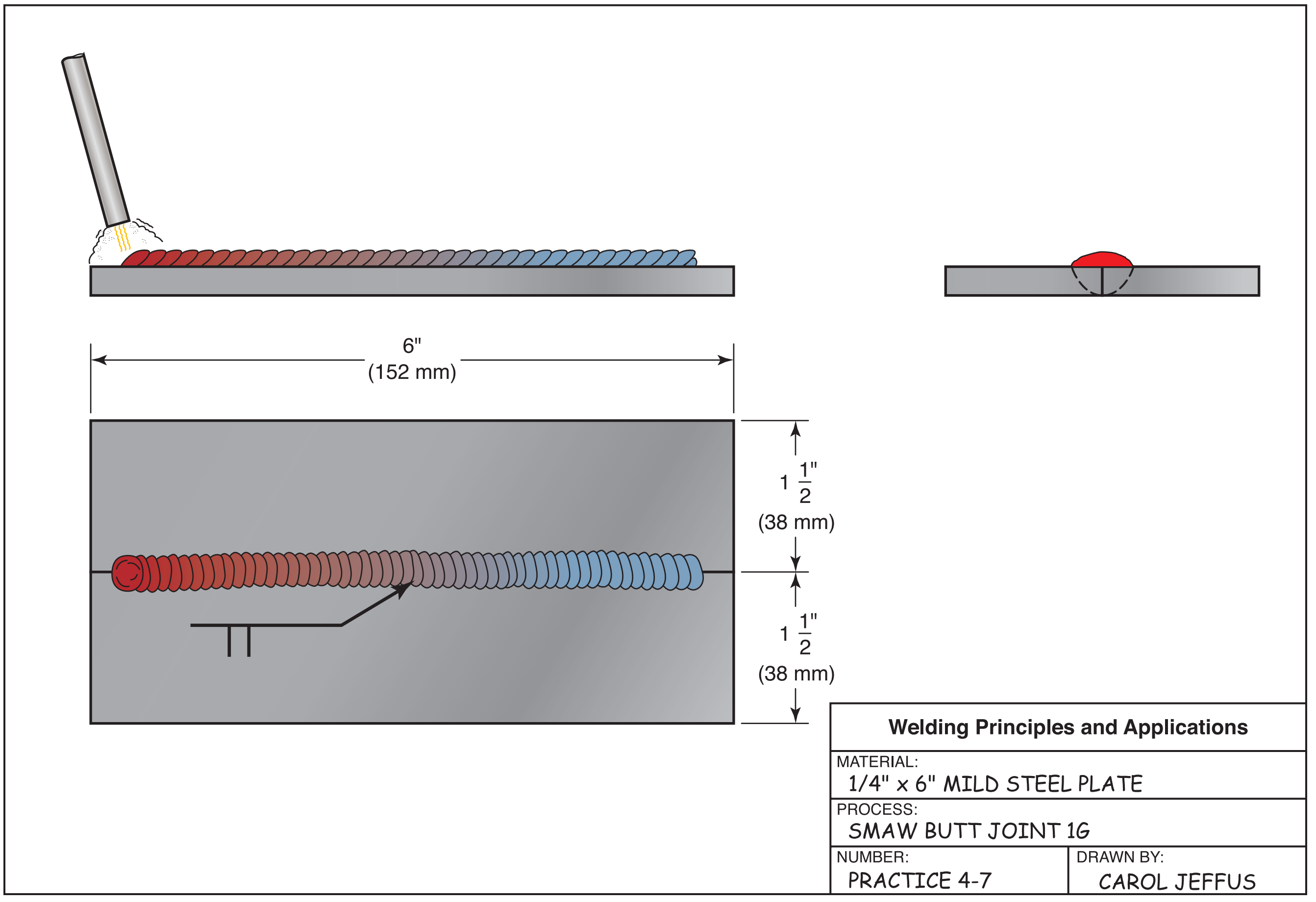
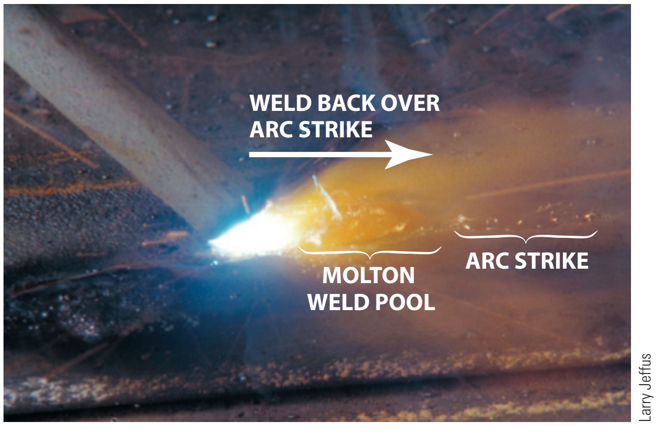
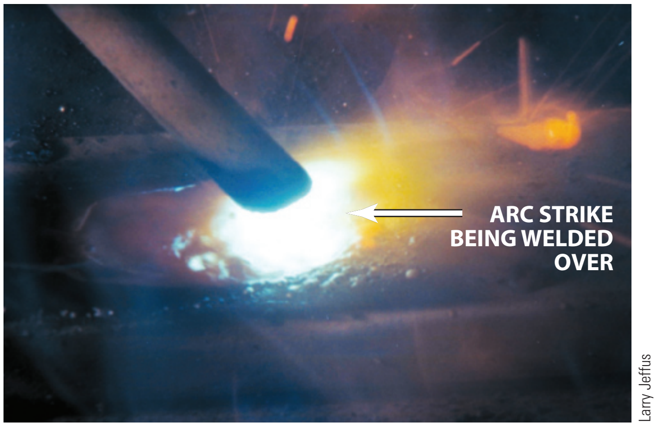


FIGURE 4-43 Square butt joint in the flat position.



(A)

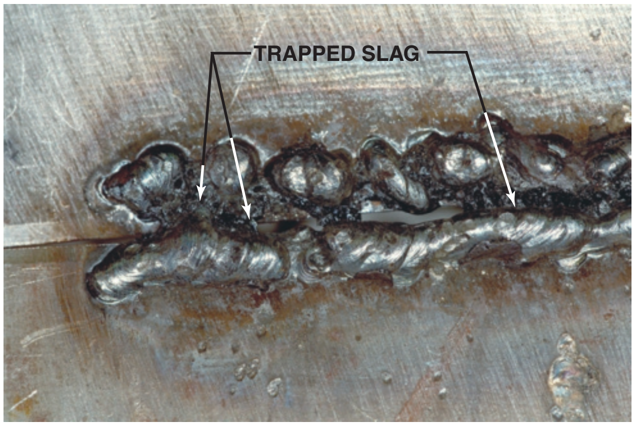


(B)

FIGURE 4-44 (A) After the arc is established, hold it in one area long enough to establish the size of molten weld pool desired. (B) Weld back over the arc strike to melt it into the weld.

With the plates at a 45° angle, start at the bottom and make the molten weld pool bridge the gap between the plates, **Figure 4-46**. Build the bead size slowly so that the molten weld pool has a shelf for support. The "C," "J," or square weave patterns work well for this joint.

As the electrode is moved up the weld, the arc is lengthened slightly so that little or no metal is deposited ahead of the molten weld pool. When the electrode is brought back into the molten weld pool, it should be lowered to deposit metal, **Figure 4-47**.



Larry Jeffus

FIGURE 4-45 Moving the electrode from side to side too quickly can result in slag being trapped between the plates.

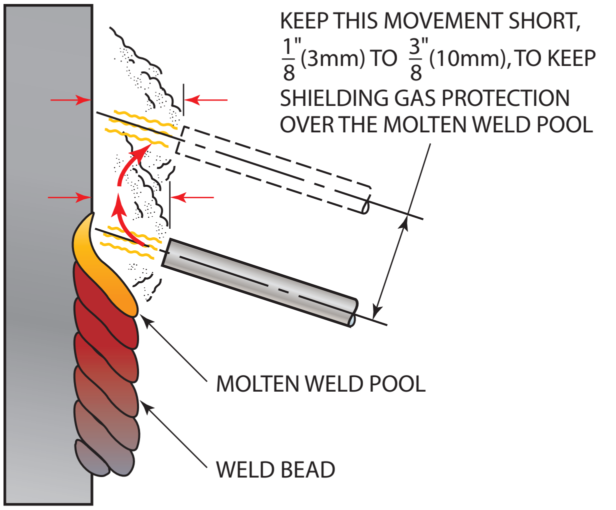


FIGURE 4-47 Electrode movement for vertical up-welds.

As skill is developed, increase the plate angle until it is vertical. Cool, chip, and inspect the weld for uniformity and defects. Repeat the welds with all three (F) groups of electrodes until you can consistently make welds free of defects. Turn off the welding machine and clean your work area when you are finished welding.

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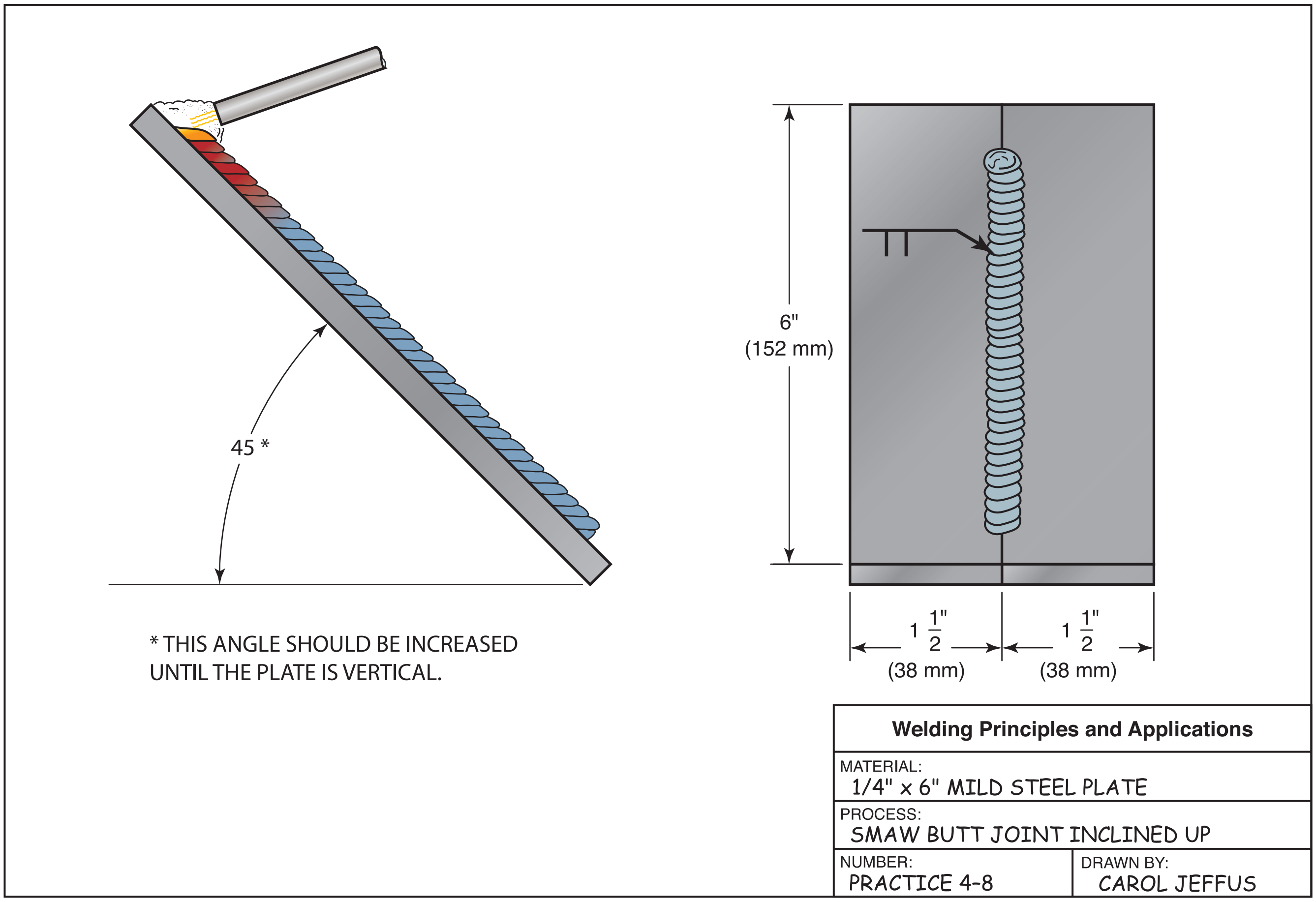

FIGURE 4-46 Square butt joint in the vertical up position.

PRACTICE 4-9

Welded Horizontal (2G) Square Butt Weld Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes

Using the same setup, materials, and electrodes as described in Practice 4-7, you will make a welded horizontal square butt joint.

- Start practicing these welds with the plate at a slight angle.
- Strike the arc on the bottom plate and build the molten weld pool until it bridges the gap.

If the weld is started on the top plate, slag will be trapped in the root at the beginning of the weld because of poor initial penetration. The slag may cause the weld to crack when it is placed in service.

The "J" weave pattern is recommended to deposit metal on the lower plate so that it can support the bead. By pushing the electrode inward as you cross the gap between the plates, deeper penetration is achieved.

As you acquire more skill, gradually increase the plate angle until it is vertical and the weld is horizontal.

- Cool, chip, and inspect the weld for uniformity and defects.
- Repeat the welds with all three (F) groups of electrodes until you can consistently make welds free of defects. Turn off the welding machine and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

EDGE WELD

Edge welds can be used to join two plate edges together. They are also much like the edge of a flange joint. Flange joints are used to join sections of pressure vassals, thin gauge metal parts, and sheet metal. An edge weld joint is made by placing the edges of the plate evenly, **Figure 4-48**. When assembling the edge joint, the plates should be clamped tightly together; there should not be any gap between the plates.

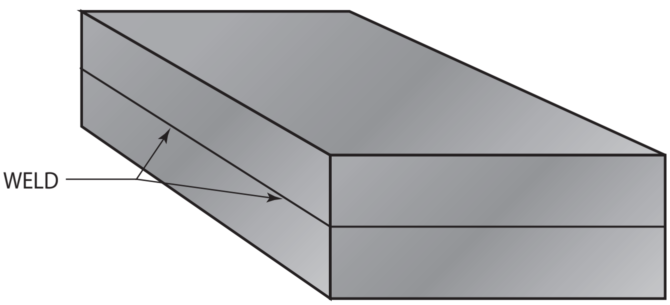

FIGURE 4-48 Edge joint.

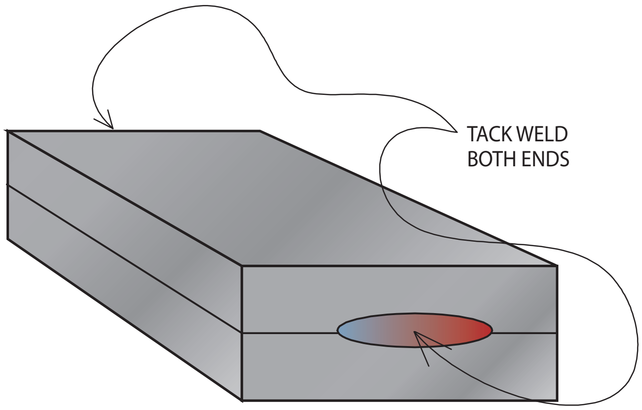

FIGURE 4-49 Make tack welds at the ends of the joint.

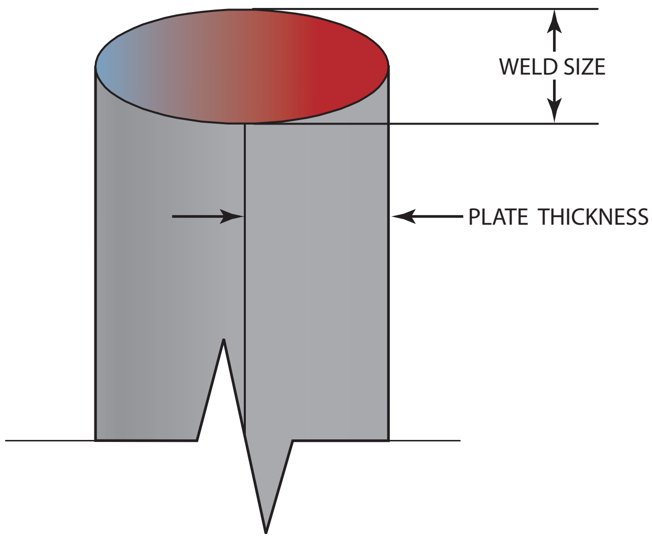

FIGURE 4-50 Edge weld size.

Both edges of the plate assembly can be welded. Make the tack welds to hold the plates together along the ends of the joint, **Figure 4-49**.

The size of the weld should equal the thickness of the plate being joined. A good indication that the weld is being made large enough is when the weld bead width is equal to the width of the joint, **Figure 4-50**. The weld bead should also have a slight buildup.

PRACTICE 4-10

Edge Weld in the Flat Position Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes

Using a properly set up and adjusted arc welding machine, proper safety protection, as demonstrated in Practice 4-1, arc welding electrodes with a 1/8 in. (3 mm) diameter, and two pieces of mild steel plate 6 in. (152 mm) long and 1/4 in. (6 mm) thick, you will make a weld on an edge joint, **Figure 4-51**.

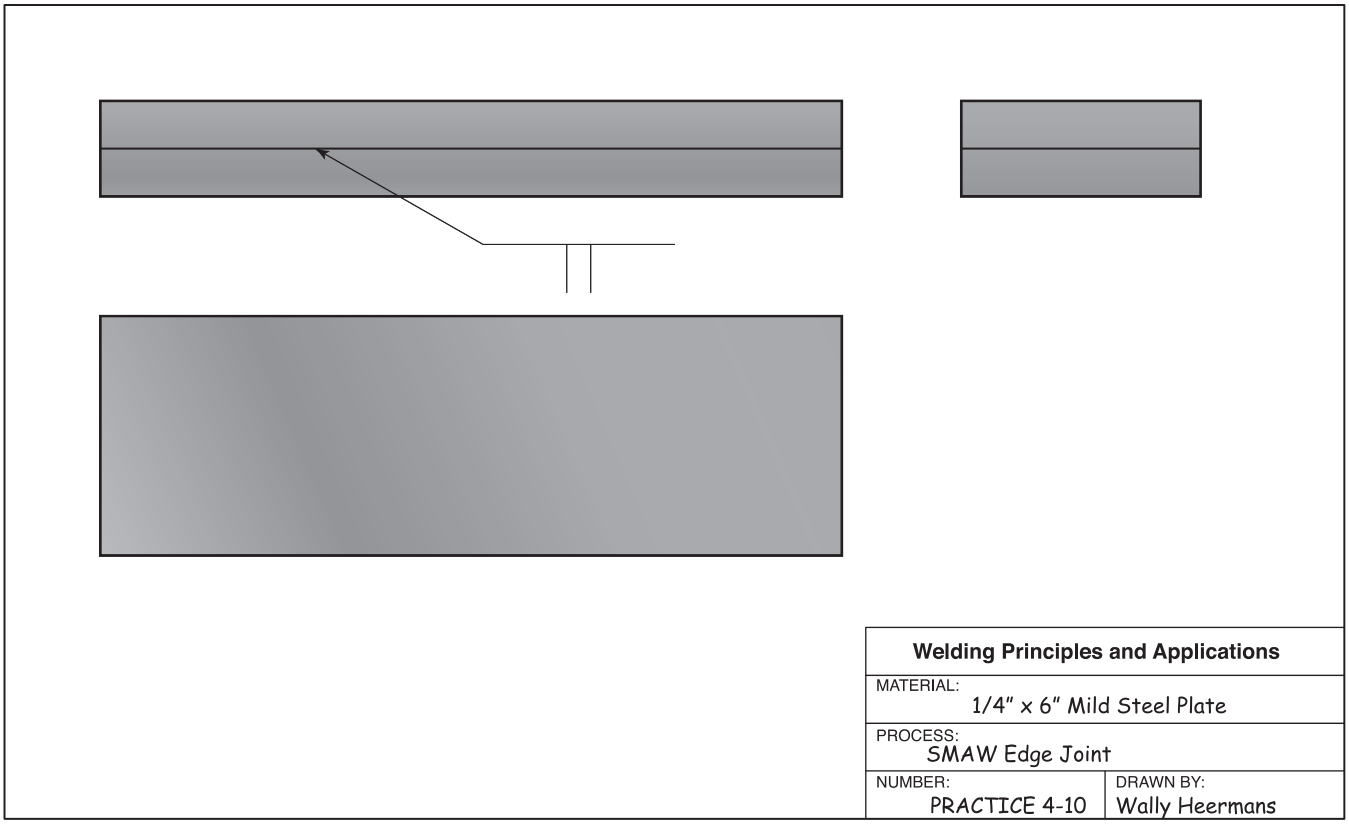

FIGURE 4-51 Practice 4-10 edge joint

- Clamp the plates flat together and make a tack weld along each end of the plates.
- Starting at one end of the plate, make a straight weld the full length of the plate. Make the weld bead as wide as the width of the edge joint.
- Watch the molten weld pool, not the end of the electrode.
- Cool, chip, and inspect the weld for uniformity and defects.
- Repeat the welds as needed with all three (F) groups of electrodes until you can consistently make welds free of defects.
- Turn off the welding machine and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 4-11

Edge Joint in the Vertical Down Position Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes

Using the same setup, materials, and electrodes as listed in Practice 4-10, you will make a vertical down-weld on an edge joint. Start with the plates at a 45° angle.

This technique is the same as that used to make vertical down-welds. However, a lower level of skill is required at 45°, and it is easier to develop your skill. After you master the 45° angle, the angle is increased successively until a vertical position is reached, **Figure 4-52**. Small changes in the amperage setting can have a large affect on downhill welds. Pipe line welders may ask a welding helper to adjust

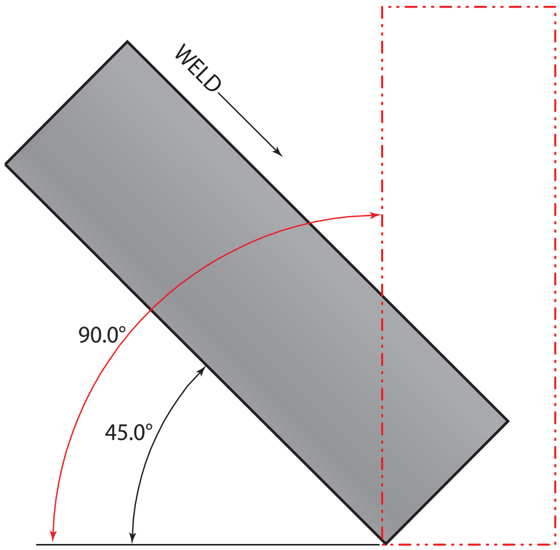

FIGURE 4-52 Vertical down-weld.

the amperage by as little as one or two amps. As you make the weld, if your welding machine can be adjusted while you are welding, then have someone make small changes in the amperage setting and see if you can tell the difference.

- Make the weld bead as wide as the joint. Controlling a weld bead this size is more difficult, but you must develop the skill required to control this larger molten weld pool.
- Cool, chip, and inspect the weld for uniformity and defects.
- Repeat the welds as needed with all three (F) groups of electrodes until you can consistently make welds free of defects. Turn off the welding machine and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 4-12

Edge Joint in the Vertical Up Position Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes

Using the same setup, materials, and electrodes as listed in Practice 4-10, you will make a vertical up-weld on an edge joint. Start with the plates at a 45° angle.

This technique is the same as that used to make vertical up-welds. However, a lower level of skill is required at 45°, and it is easier to develop your skill. After you master the 45° angle, the angle is increased successively until a vertical position is reached, **Figure 4-53**.

Before the molten metal drips down the bead, the back of the molten weld pool will start to bulge, **Figure 4-54**. When this happens, increase the speed of travel and the weave pattern.

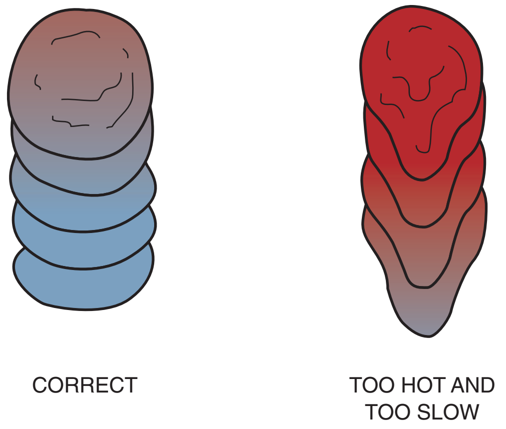

FIGURE 4-54 Watch the trailing edge of the weld pool to judge the correct travel speed.

- Cool, chip, and inspect the weld for uniformity and defects.
- Repeat the welds as needed with all three (F) groups of electrodes until you can consistently make welds free of defects. Turn off the welding machine and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 4-13

Edge Joint in the Horizontal Position Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes

Using the same setup, materials, and electrodes as listed in Practice 4-10, you will make a horizontal weld on an edge joint. When you begin to practice the horizontal weld, the plate may be reclined slightly, **Figure 4-55**. This placement

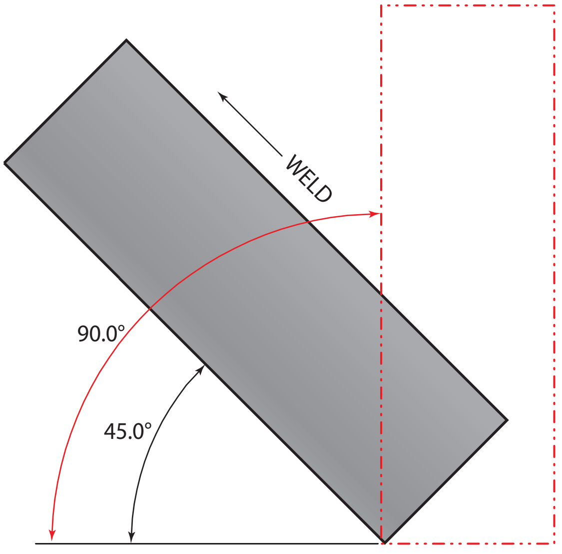

FIGURE 4-53 Vertical up-weld.

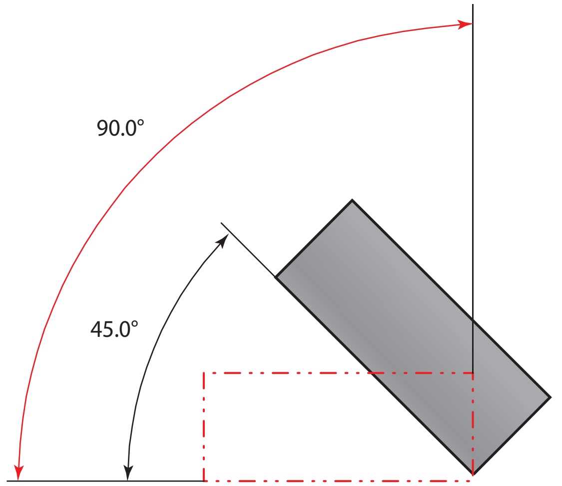

FIGURE 4-55 Incline angle.

allows the welder to build the required skill by practicing the correct techniques successfully. The "J" weave or stepped pattern is suggested for this practice. As the electrode is drawn back to the back edge of the weld pool, metal is deposited. Use the metal being deposited to support the molten weld pool.

Angling the electrode up and back toward the weld causes more metal to be deposited along the top edge of the weld. Keeping the bead small allows the surface tension to hold the molten weld pool in place.

Gradually increase the angle of the plate until it and the weld bead are horizontal.

- Cool, chip, and inspect the weld for uniformity and defects.
- Repeat the welds as needed with all three (F) groups of electrodes until you can consistently make welds free of defects. Turn off the welding machine and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 4-14

Edge Joint in the Overhead Position Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes

Using the same setup, materials, and electrodes as listed in Practice 4-10, you will make an overhead weld on an edge joint.

- With the electrode pointed in a slightly trailing angle, **Figure 4-56**, strike the arc in the joint.
- Keep a very short arc length.

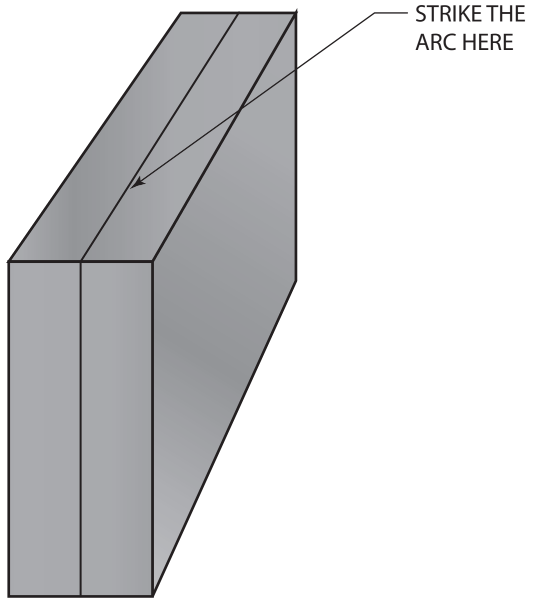

FIGURE 4-56 Strike the arc in the joint.

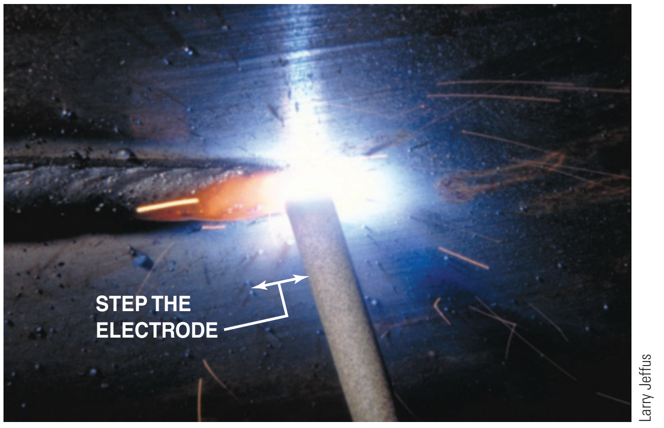

FIGURE 4-57 Step the electrode.

- Use the stepped pattern and move the electrode forward slightly when the molten weld pool grows to the correct size, **Figure 4-57**.

As the molten weld pool gets larger it has a tendency to quickly become convex. If you keep the arc in the molten weld pool once the joint is filled and the weld face is flat, it will quickly overfill and become convex. This can result in the weld face forming drips of metal hanging from the weld like icicles, **Figure 4-58**.

- When the molten weld pool cools and begins to shrink, move the arc back near the center of the weld.
- Hold the arc in this new location until the molten weld pool again grows to the correct size.
- Step the electrode forward again and keep repeating this pattern until the weld progresses along the entire weld joint length.

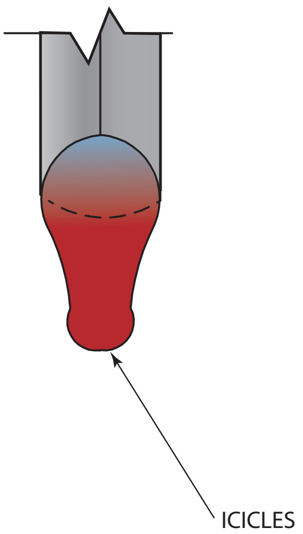

FIGURE 4-58 Welding too slow or with too high of an amperage setting will result in the weld metal dripping down like icicles.

- Cool, chip, and inspect the weld for uniformity and defects.
- Repeat the welds as needed with all three (F) groups of electrodes until you can consistently make welds free of defects. Turn off the welding machine and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

OUTSIDE CORNER JOINT

An outside corner joint is made by placing the plates at a 90° angle to each other, with the edges forming a V-groove, **Figure 4-59**. There may or may not be a slight root opening left between the plate edges. Small tack welds should be made approximately 1/2 in. (13 mm) from both ends of the joint.

The weld bead should completely fill the V-groove formed by the plates and may have a slightly convex surface buildup. The back side of an outside corner joint can be used to practice fillet welds, or four plates can be made into a box tube shape, **Figure 4-60**.

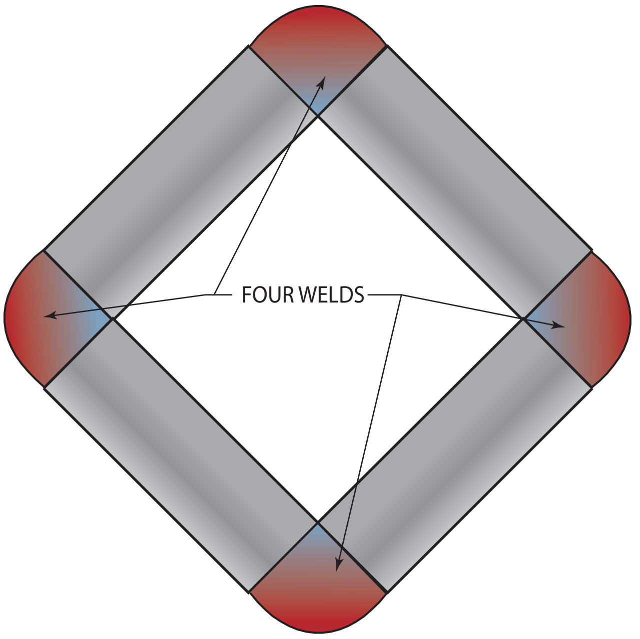

FIGURE 4-60 Box tube made from four outside corner joint welds.

PRACTICE 4-15

Outside Corner Joint in the Flat Position Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes

Using a properly set up and adjusted arc welding machine, proper safety protection, as demonstrated in Practice 4-1, arc welding electrodes with a 1/8 in. (3 mm) diameter, and two pieces of mild steel plate 6 in. (152 mm) long and 1/4 in. (6 mm) thick, you will make a weld on an outside corner joint.

- Starting at one end of the plate, make a straight weld the full length of the plate.
- Watch the molten weld pool at this point, not the end of the electrode. As you become more skillful, it is easier to watch the molten weld pool.

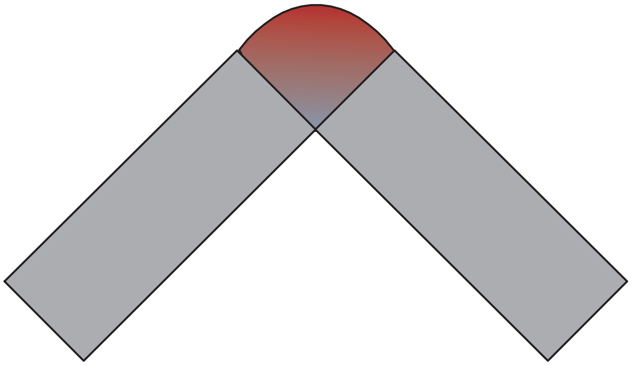

FIGURE 4-59 V formed by an outside corner joint.

- Cool, chip, and inspect the weld for uniformity and defects.
- Repeat the welds as needed with all three (F) groups of electrodes until you can consistently make welds free of defects. Turn off the welding machine and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 4-16

Outside Corner Joint in the Vertical Down Position Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes

Using the same setup, materials, and electrodes as listed in Practice 4-15, you will make a vertical down-weld on an outside corner joint. Start with the plate at a 45° angle.

This technique is the same as that used to make vertical down-welds. However, a lower level of skill is required at 45°, and it is easier to develop your skill. After you master the 45° angle, the angle is increased successively until a vertical position is reached, **Figure 4-61**.

- Cool, chip, and inspect the weld for uniformity and defects.
- Repeat the welds as needed with all three (F) groups of electrodes until you can consistently make welds free of defects. Turn off the welding machine and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

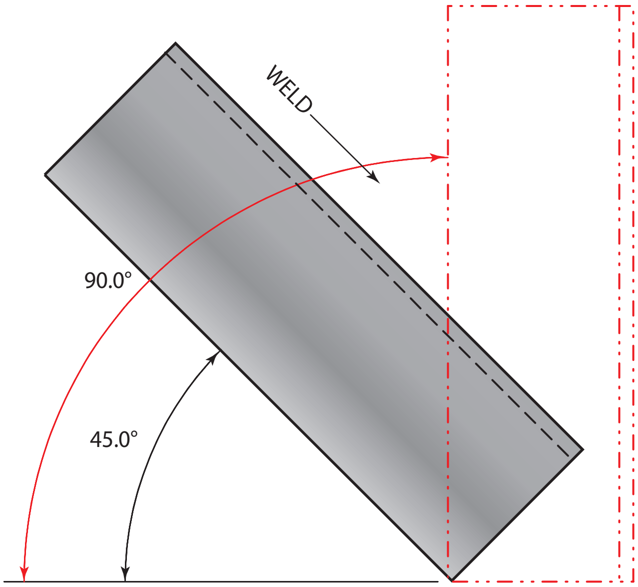

FIGURE 4-61 Start with a 45° angle and increase it to 90°.

PRACTICE 4-17

Outside Corner Joint in the Vertical Up Position Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes

Using the same setup, materials, and electrodes as listed in Practice 4-15, you will make a vertical up-weld on an outside corner joint. Start with the plate at a 45° angle.

This technique is the same as that used to make vertical up-welds. However, a lower level of skill is required at 45°, and it is easier to develop your skill. After the welder masters the 45° angle, the angle is increased successively until a vertical position is reached, **Figure 4-62**.

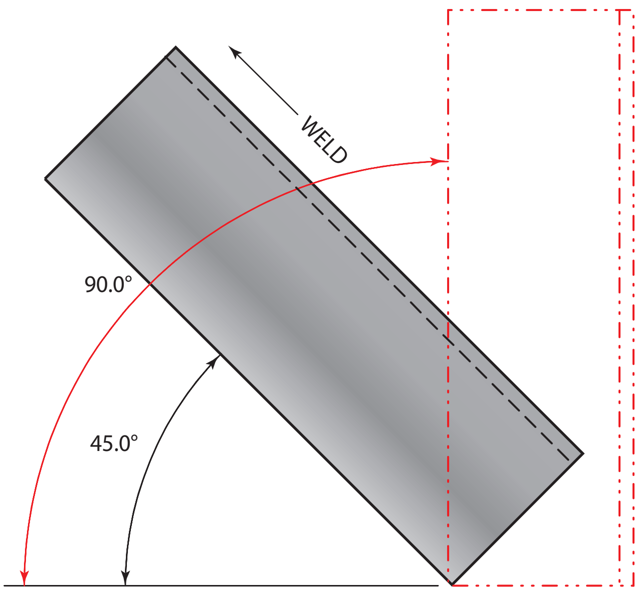

FIGURE 4-62 Vertical up-weld.

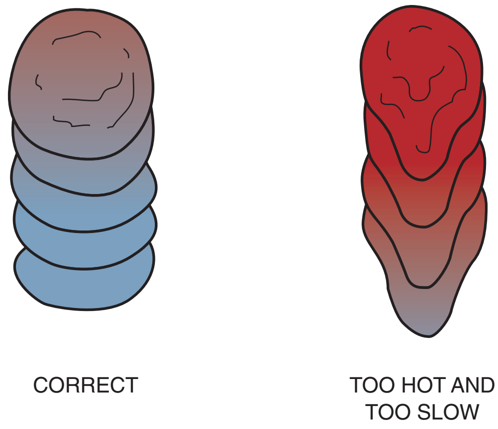

FIGURE 4-63 Watch the trailing edge of the weld pool to judge the correct travel speed.

Before the molten metal drips down the bead, the back of the molten weld pool will start to bulge, **Figure 4-63**. When this happens, increase the speed of travel and the weave pattern.

- Cool, chip, and inspect the weld for uniformity and defects.
- Repeat the welds as needed with all three (F) groups of electrodes until you can consistently make welds free of defects. Turn off the welding machine and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 4-18

Outside Corner Joint in the Horizontal Position Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes

Using the same setup, materials, and electrodes as listed in Practice 4-15, you will make a horizontal weld on an outside corner joint. When the welder begins to practice the horizontal weld, the joint may be reclined slightly, **Figure 4-64**. This placement allows the welder to build the required skill by practicing the correct techniques successfully. The "J" weave or stepped pattern is suggested for this practice. As the electrode is drawn back into the weld pool, metal is deposited. This metal supports the molten weld pool, resulting in a bead with a uniform contour, **Figure 4-65**.

Angling the electrode up and back toward the weld causes more metal to be deposited along the top edge of the weld. Keeping the bead small allows the surface tension to hold the molten weld pool in place.

Gradually increase the angle of the plate until it is vertical and the weld bead is horizontal.

- Cool, chip, and inspect the weld for uniformity and defects.

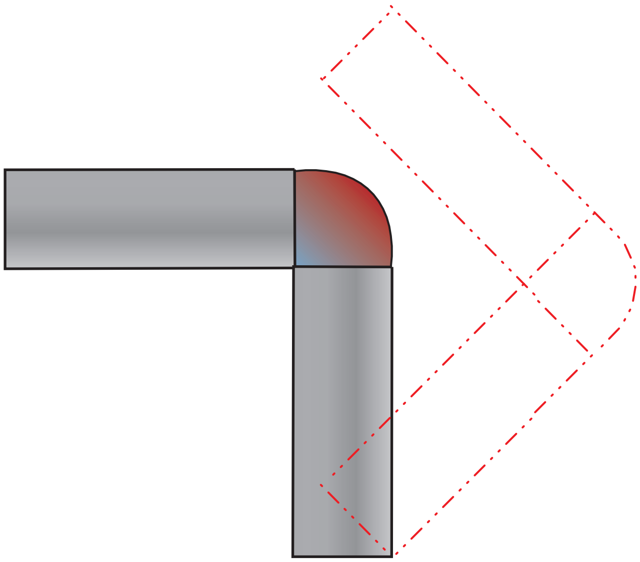

FIGURE 4-64 Incline angle.

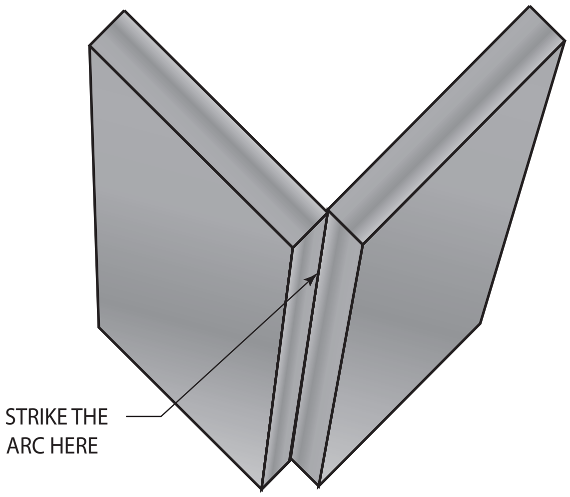

FIGURE 4-66 Strike arc in the joint.

FIGURE 4-65 J weave or stepping.

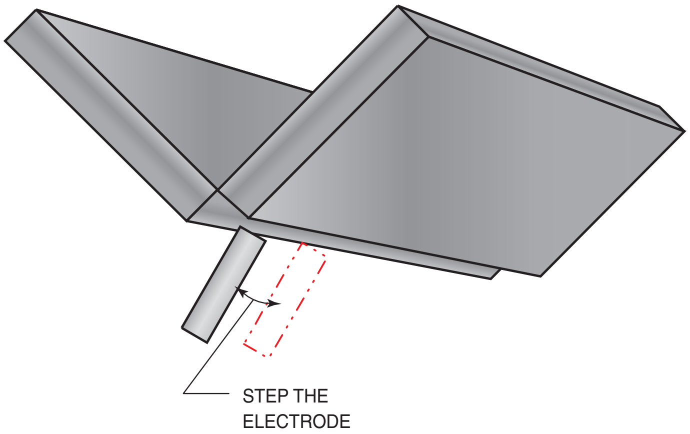

FIGURE 4-67 Stepping the electrode to control weld size.

- Repeat the welds as needed with all three (F) groups of electrodes until you can consistently make welds free of defects. Turn off the welding machine and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 4-19

Outside Corner Joint in the Overhead Position Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes

Using the same setup, materials, and electrodes as listed in Practice 4-15, you will make an overhead-welded outside corner joint.

- With the electrode pointed slightly into the joint, **Figure 4-66**, strike the arc in the joint.
- Keep a very short arc length.
- Use the stepped pattern and move the electrode forward slightly when the molten weld pool grows to the correct size, **Figure 4-67**.

As the molten weld pool gets larger, it has a tendency to quickly become convex. If you keep the arc in the molten weld pool once the joint is filled and the weld face is flat, then it will quickly overfill and become convex. This can result in the weld face forming drips of metal hanging from the weld like icicles, **Figure 4-68**.

- When the molten weld pool cools and begins to shrink, move the arc back near the center of the weld.
- Hold the arc in this new location until the molten weld pool again grows to the correct size.
- Step the electrode forward again and keep repeating this pattern until the weld progresses along the entire weld joint length.
- Cool, chip, and inspect the weld for uniformity and defects.
- Repeat the welds as needed with all three (F) groups of electrodes until you can consistently make welds free of defects. Turn off the welding machine and clean your work area when you are finished welding.

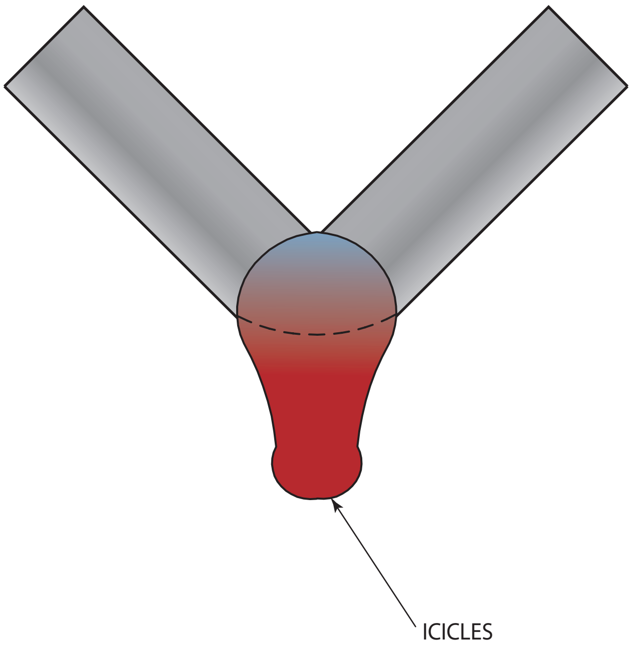

FIGURE 4-68 Welding too slow or with too high of an amperage setting will result in the weld metal dripping down like icicles.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

LAP JOINT

A **lap joint** is made by overlapping the edges of two plates, **Figure 4-69**. The joint can be welded on one side or both sides with a fillet weld. In Practice 4-20, both sides should be welded unless otherwise noted.

As the fillet weld is made on the lap joint, the buildup should equal the thickness of the plate, **Figure 4-70**. A good weld will have a smooth transition from the plate surface to the weld. If this transition is abrupt, then it can cause stresses that will weaken the joint.

Penetration for lap joints does not improve their strength; complete fusion is required. The root of fillet welds must be melted to ensure a completely fused joint. If the molten weld pool shows a notch at the leading edge where the plates form the root of the joint during the weld, **Figure 4-71**, then this is an indication that the root is not being fused together. The weave pattern will help prevent this problem, **Figure 4-72**.

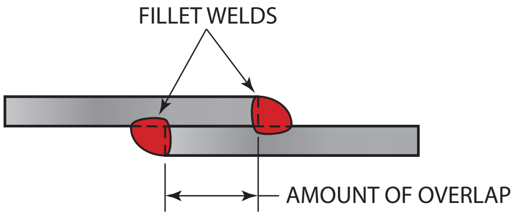

FIGURE 4-69 Lap joint.

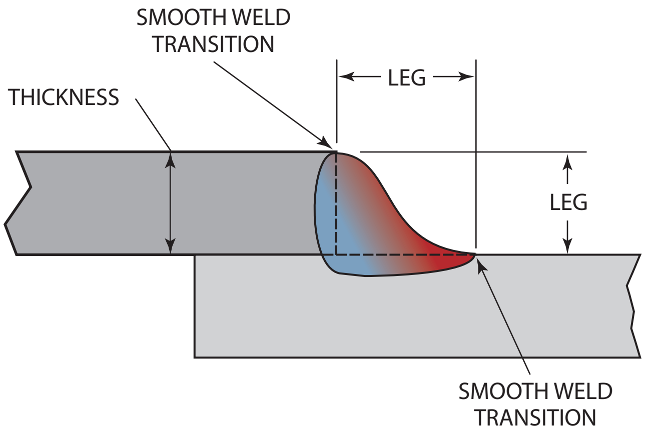

FIGURE 4-70 The legs of a fillet weld generally should be equal to the thickness of the base metal.

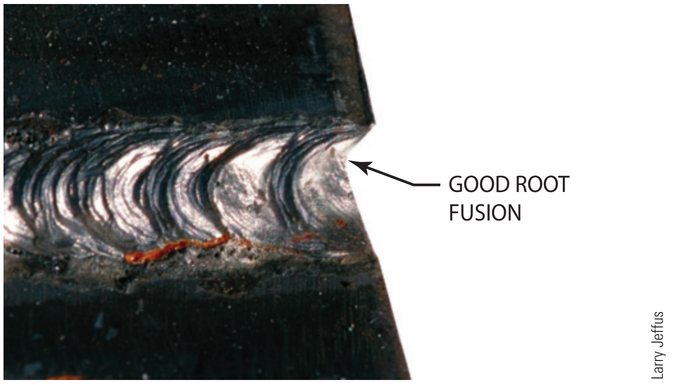

FIGURE 4-71 Watch the root of the weld bead to be sure there is complete fusion.

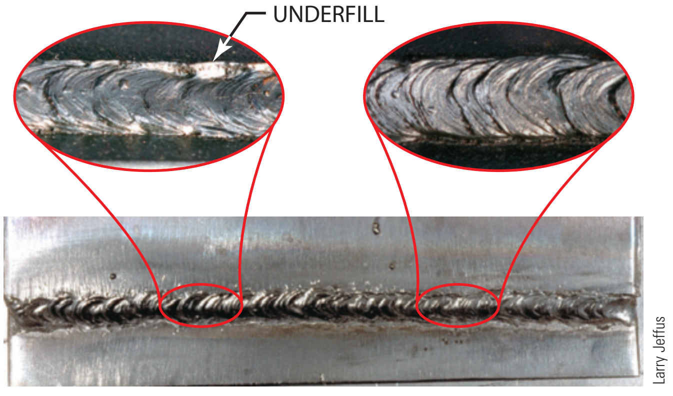

FIGURE 4-72 Lap joint.

PRACTICE 4-20

Welded Lap Joint in the Flat Position (1F) Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes

Using a properly set up and adjusted arc welding machine, proper safety protection, arc welding electrodes with a 1/8 in.

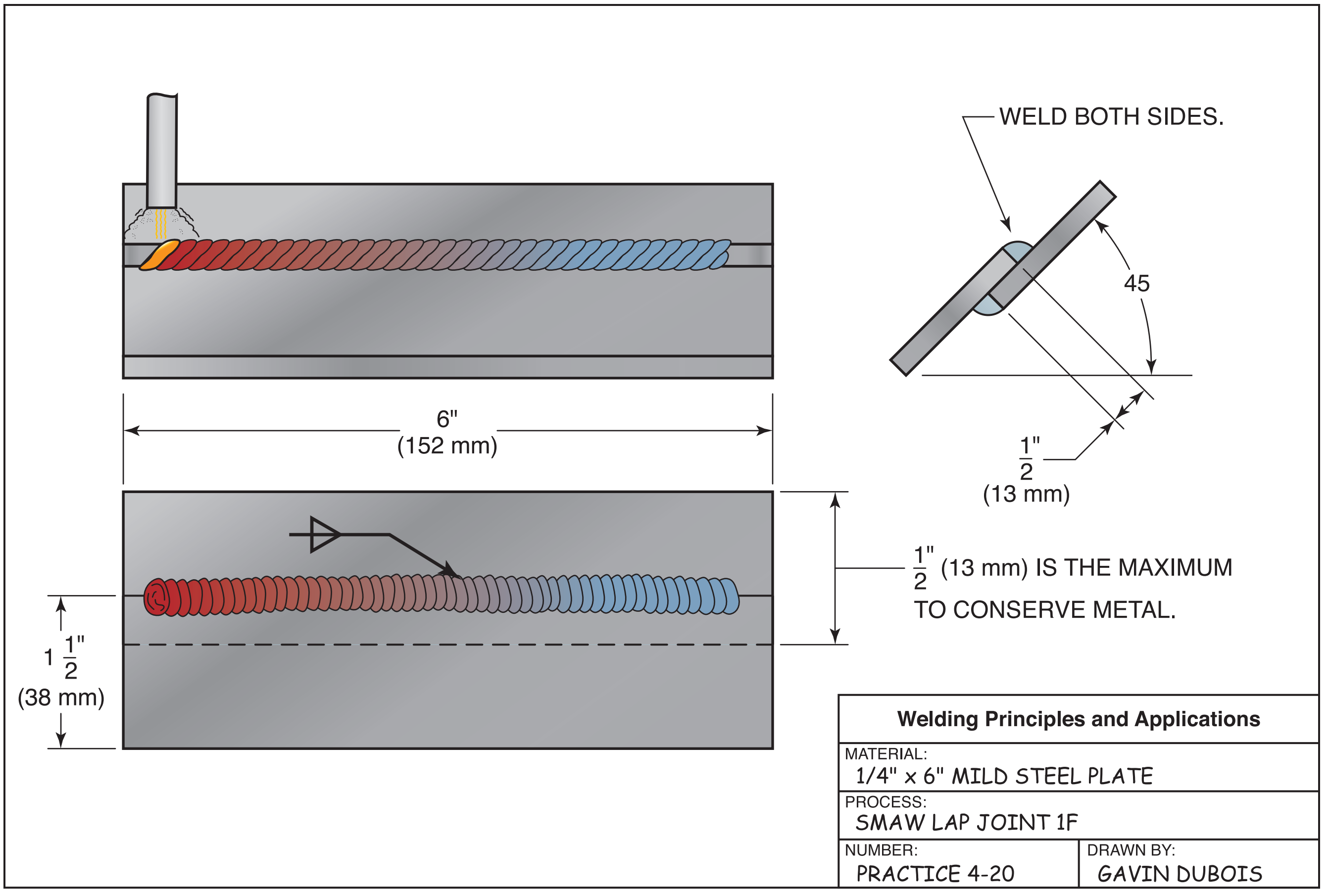

FIGURE 4-73 Lap joint in the flat position.

(3 mm) diameter, and two or more pieces of mild steel plate 6 in. (152 mm) long and 1/4 in. (6 mm) thick, you will make a welded lap joint in the flat position, **Figure 4-73**.

Hold the plates together tightly with an overlap of no more than 1/4 in. (6 mm). Tack weld the plates together. A small tack weld may be added in the center to prevent distortion during welding, **Figure 4-74**. Chip the tacks before you start to weld.

The "J," "C," or zigzag weave patterns work well on this joint. Strike the arc and establish a molten pool directly in the joint. Move the electrode out on the bottom plate and then onto the weld to the top edge of the top plate, **Figure 4-75**. Follow the surface of the plates with the arc. Do not follow the trailing edge of the weld bead. Following the molten weld pool will not allow for good root fusion and will cause slag to collect in the root. If slag does collect, then a good weld is not

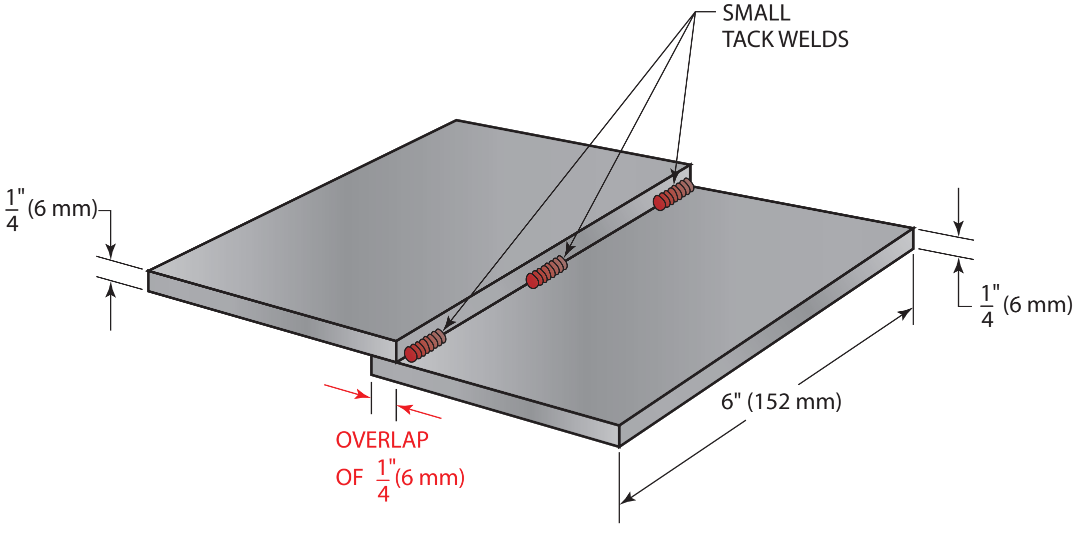

FIGURE 4-74 Tack welding the plates together.

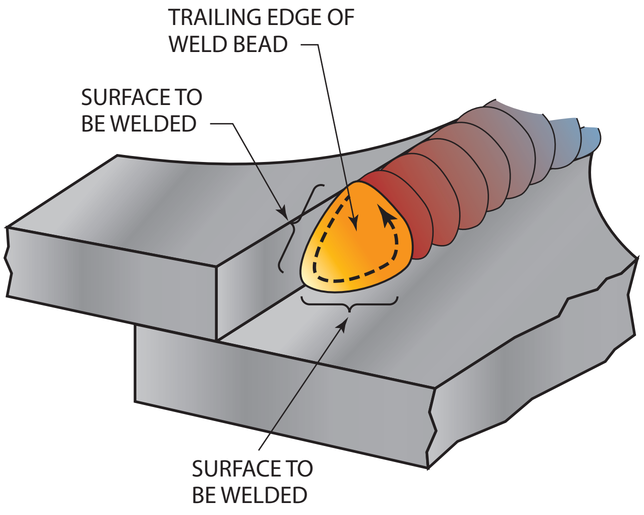

FIGURE 4-75 Follow the surface of the plate to ensure good fusion.

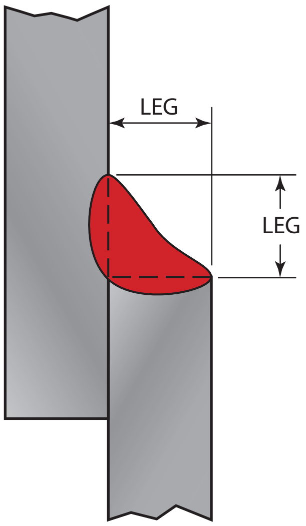

FIGURE 4-76 The horizontal lap joint should have a fillet weld that is equal on both plates.

possible. Stop welding and chip the slag to remove it before continuing the weld. Cool, chip, and inspect the weld for uniformity and defects. Repeat the welds with all three (F) groups of electrodes until you can consistently make welds free of defects. Turn off the welding machine and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 4-21

Welded Lap Joint in the Horizontal Position (2F) Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes

Using the same setup, materials, and electrodes as listed in Practice 4-20, you will make a welded horizontal lap joint.

The horizontal lap joint and the flat lap joint require nearly the same technique and skill to achieve a proper weld, **Figure 4-76**. Use the "J," "C," or zigzag weave patterns to make the weld. Do not allow slag to collect in the root. The fillet must be equally divided between both plates for good strength. After completing the weld, cool, chip, and inspect the weld for uniformity and defects. Repeat the welds using all three (F) groups of electrodes until you can consistently make welds free of defects. Turn off the welding machine and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 4-22

Lap Joint in the Vertical Position (3F) Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes

Using the same setup, materials, and electrodes as listed in Practice 4-20, you will make a vertical up-welded lap joint.

- Start practicing this weld with the plate at a 45° angle.
- Gradually increase the angle of the plate to vertical as skill is gained in welding this joint. The "J" or "T" weave patterns work well on this joint.
- Establish a molten weld pool in the root of the joint.
- Use the "T" pattern to step ahead of the molten weld pool, allowing it to cool slightly. Do not deposit metal ahead of the molten weld pool.
- As the molten weld pool size starts to decrease, move the electrode back down into the molten weld pool.
- Quickly move the electrode from side to side in the molten weld pool, filling up the joint.
- Cool, chip, and inspect the weld for uniformity and defects.
- Repeat the welds as necessary with all three (F) groups of electrodes until you can consistently make welds free of defects. Turn off the welding machine and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 4-23

Lap Joint in the Overhead Position (4F) Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes

Using the same setup, materials, and electrodes as listed in Practice 4-20, you will make an overhead-welded lap joint.

- With the electrode pointed slightly into the joint, **Figure 4-77**, strike the arc in the inside corner of the lap joint.
- Keep a very short arc length.
- Use the stepped pattern and move the electrode forward slightly when the molten weld pool grows to the correct size, **Figure 4-78**.

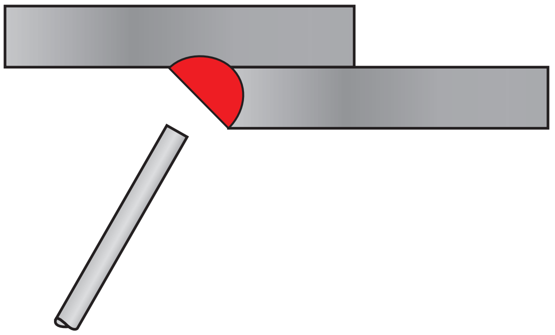

FIGURE 4-77 Point the electrode slightly toward the root of the joint.

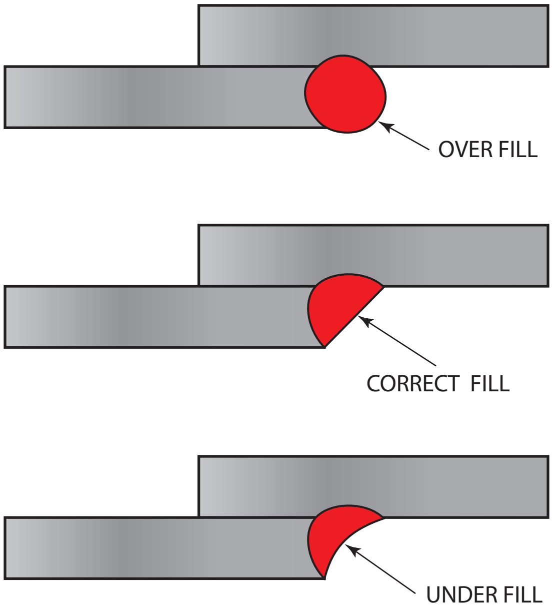

FIGURE 4-78 Correct fillet weld size for overhead welds.

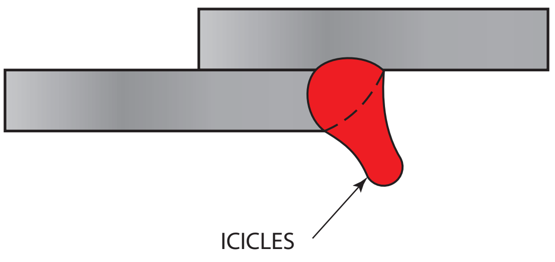

FIGURE 4-79 Overfilling the molten weld pool will result in drips of metal called icicles.

As the molten weld pool gets larger it has a tendency to quickly become convex. If you keep the arc in the molten weld pool once the joint is filled and the weld face is flat, then it will quickly overfill and become convex. This can result in the weld face forming drips of metal hanging from the weld like icicles, **Figure 4-79**.

- When the molten weld pool cools and begins to shrink, move the arc back near the center of the weld.
- Hold the arc in this new location for a fraction of a second until the molten weld pool again grows to the correct size.
- Step the electrode forward again and keep repeating this pattern until the weld progresses along the entire weld joint length.
- Cool, chip, and inspect the weld for uniformity and defects.
- Repeat the welds as needed with all three (F) groups of electrodes until you can consistently make welds free of defects. Turn off the welding machine and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

TEE JOINT

The **tee joint** is made by tack welding one piece of metal on another piece of metal at a right angle, **Figure 4-80**. After the joint is tack welded together, the slag is chipped from the tack welds. If the slag is not removed, it will cause a slag inclusion in the final weld.

The heat is not distributed uniformly between both plates during a tee weld. Because the plate that forms the stem of the tee can conduct heat away from the arc in only one direction, it will heat up faster than the base plate. Heat escapes into the base plate in two directions. When using a weave pattern, most of the heat should be directed to the base plate to keep the weld size more uniform and to help prevent an undercut.

A welded tee joint can be strong if it is welded on both sides, even without having deep penetration, **Figure 4-81**. The weld will be as strong as the base plate if the size of the two welds equals the total thickness of the base plate. The

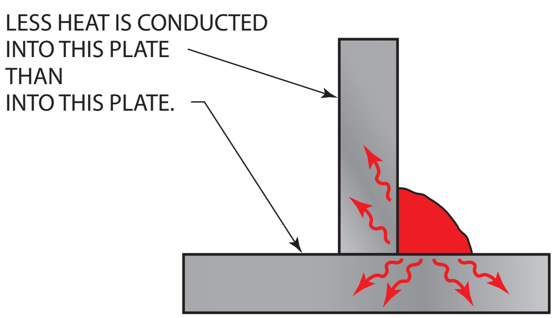

FIGURE 4-80 Tee joint.

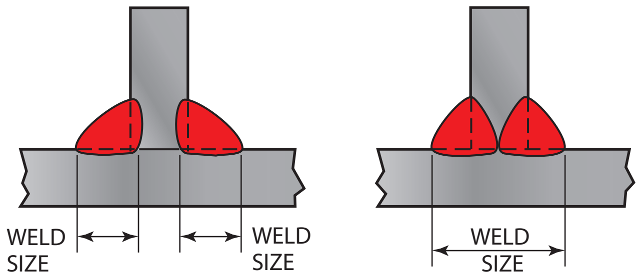

FIGURE 4-81 If the total weld sizes are equal, then both tee joints would have equal strength.

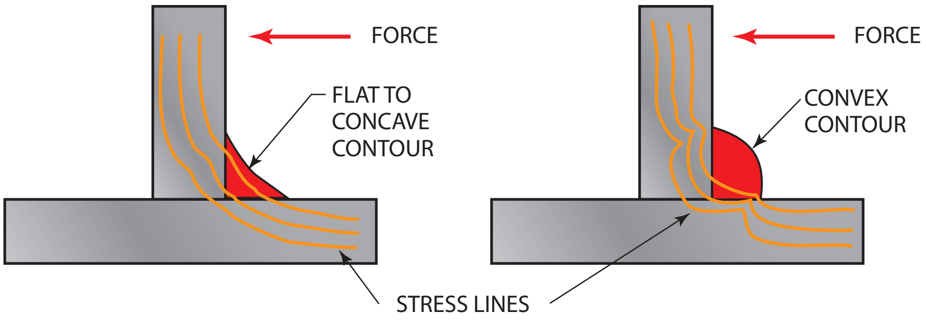

FIGURE 4-82 The stresses are distributed more uniformly through a flat or concave fillet weld.

weld bead should have a flat or slightly concave appearance to ensure the greatest strength and efficiency, **Figure 4-82**.

PRACTICE 4-24

Tee Joint in the Flat Position (1F) Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes

Using a properly set up and adjusted arc welding machine, proper safety protection, arc welding electrodes with a 1/8 in. (3 mm) diameter, and two or more pieces of mild steel plate 6 in. (152 mm) long and 1/4 in. (6 mm) thick, you will make a welded tee joint in the flat position, **Figure 4-83**.

After the plates are tack welded together, place them on the welding table so the weld will be flat. Start at one end and establish a molten weld pool on both plates. Allow the molten weld pool to flow together before starting the bead. Any of the weave patterns will work well on this joint. To prevent slag inclusions, use an amperage setting that is slightly higher than normal.

When the 6-in. (152-mm) -long weld is completed, cool, chip, and inspect it for uniformity and soundness. Repeat the welds as needed for all these groups of electrodes

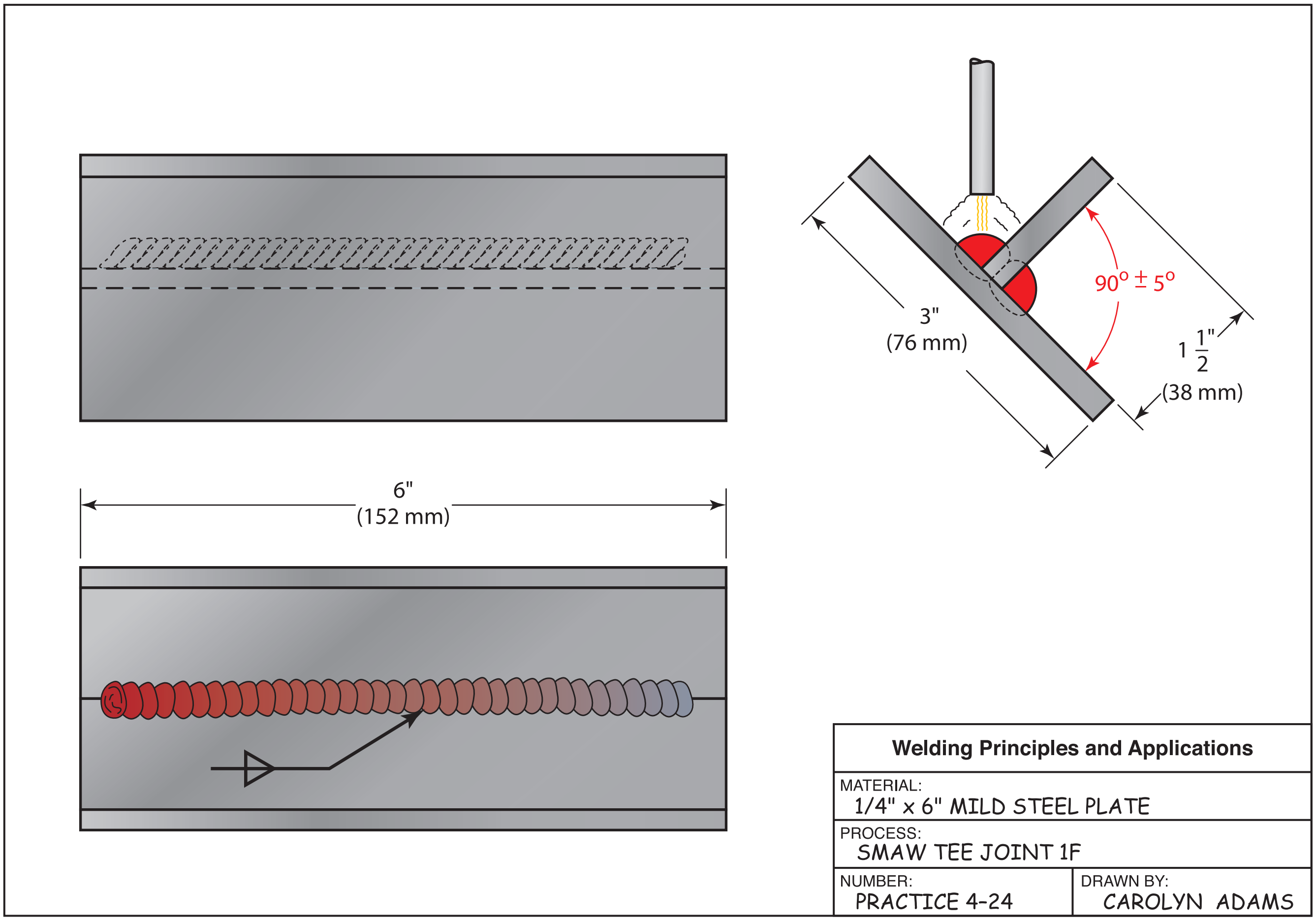

FIGURE 4-83 Tee joint in the flat position.

until you can consistently make welds free of defects. Turn off the welding machine and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 4-25

Tee Joint in the Horizontal Position (2F) Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes

Using the same setup, materials, and electrodes as listed in Practice 4-24, you will make a welded tee joint in the horizontal position.

Place the tack welded tee plates flat on the welding table so that the weld is horizontal and the plates are flat and vertical, **Figure 4-84**. Start the arc on the flat plate and establish a molten weld pool in the root on both plates. Using the "J" or "C" weave patterns, push the arc into the root and slightly up the vertical plate. You must keep the root of the joint fusing together with the weld metal. If the metal does not fuse, a notch will appear on the leading edge of the weld bead. Poor or incomplete root fusion will cause the weld to be weak and easily cracked under a load.

When the weld is completed, cool, chip, and inspect it for uniformity and defects. Undercut on the vertical plate is the most common defect. Repeat the welds with all three (F) groups of electrodes until you can consistently make welds free of defects. Turn off the welding machine and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 4-26

Tee Joint in the Vertical Position (3F) Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes

Using the same setup, materials, and electrodes as listed in Practice 4-24, you will make a welded tee joint in the vertical position.

Practice this weld with the plate at a 45° angle. This position will allow you to develop your skill for the vertical

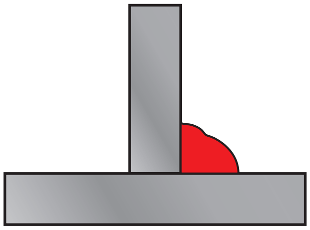

FIGURE 4-84 Horizontal tee.

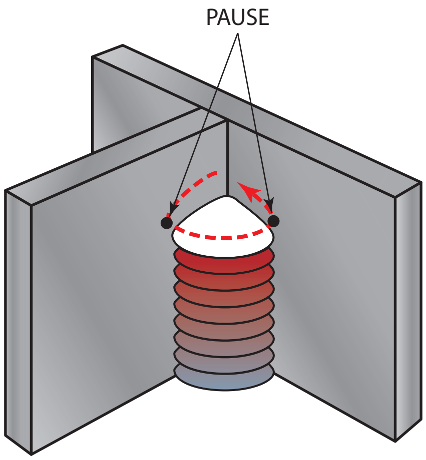

FIGURE 4-85 Pausing just above the undercut will fill it. This action also causes undercut, but that will be filled on the next cycle.

position. Start the arc and molten weld pool deep in the root of the joint. Build a shelf large enough to support the bead as it progresses up the joint. The square, "J," or "C" patterns can be used, but the "T" or stepped patterns will allow deeper root penetration.

For this weld, undercut is a problem on both sides of the weld. It can be controlled by holding the arc on the side long enough for filler metal to flow down and fill it, **Figure 4-85**. Cool, chip, and inspect the weld for uniformity and defects. Repeat the welds as necessary with all three (F) groups of electrodes until you can consistently make welds free of defects. Turn off the welding machine and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 4-27

Tee Joint in the Overhead Position (4F) Using E6010 or E6011 Electrodes, E6012 or E6013 Electrodes, and E7016 or E7018 Electrodes

Using the same setup, materials, and electrodes as listed in Practice 4-14, you will make a welded tee joint in the overhead position.

Start the arc and molten weld pool deep in the root of the joint. Keep a very short arc length. The stepped pattern will allow deeper root penetration.

For this weld, undercut is a problem on both sides of the weld, with a high buildup in the center. It can be controlled by holding the arc on the side long enough for filler metal to flow in and fill the undercut. Cool, chip, and inspect the weld for uniformity and defects. Repeat the welds as necessary with all three (F) groups of electrodes until you can consistently make welds free of defects. Turn off the welding machine and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

Summary

The shielded metal arc welding process is most often referred to in welding shops as stick welding. Some people say that it gets this name for one of two reasons. The first is most obviously as a result of the stick shape of the electrode. The second reason is experienced by all new welders; it is the tendency for the electrode to stick to the workpiece. All new welders experience this, and your ability to control the sticking of the electrode can be improved as you develop the proper arc-striking techniques.

For a new welder, it is often difficult to concentrate on anything other than the bright sparks and glow at the end of the electrode. But, with time, as you develop your skills, your visual field will increase, allowing you to see a much larger welding zone. This skill comes with time and practice. Developing this skill is essential for you to become a highly proficient welder. Nothing enhances your welding skills more than time under the hood, actually welding, cleaning the weld, inspecting it, determining the necessary corrections to be made, and immediately trying to produce the next weld with a higher level of quality.

Review

1. Describe two methods of striking an arc with an electrode.
2. Why is it important to strike the arc only in the weld joint?
3. What problems may result by using an electrode at too low of a current setting?
4. What problems may result by using an electrode at too high of a current setting?
5. According to Table 4-1, what would the amperage range be for the following electrodes?
   a. 1/8 in. (3.2 mm), E6010 (70-130)
   b. 5/32 in. (4 mm), E7018 (125-220)
   c. 3/32 in. (2.4 mm), E7016 (75-105)
   d. 1/8 in. (3.2 mm), E6011 (85-125)
6. What makes some spatter “hard?”
7. Why should you never change the current setting during a weld?
8. What factors should be considered when selecting an electrode size?
9. What can a welder do to control overheating of the metal pieces being welded?
10. What problems can result from too long or too short of an arc length?
11. What arc problems can occur in deep or narrow weld joints?
12. Describe the difference between using a leading and a trailing electrode angle.
13. Can all electrodes be used with a leading angle? Why or why not?
14. What characteristics of the weld bead does the weaving of the electrode cause?
15. What are some of the applications for the circular pattern in the flat position?
16. Using a pencil and paper, draw two complete lines of the weave patterns you are most comfortable making.
17. Why is it important to find a good welding position?
18. Which electrodes would be grouped in the following F numbers: F3, F2, F4?
19. Give one advantage of using electrodes with cellulose-based fluxes.
20. What are stringer beads?
21. Describe an ideal tack weld.
22. What effect does the root opening or root gap have on a butt joint?
23. What can happen if the fillet weld on a lap joint does not have a smooth transition?
24. Which plate heats up faster on a tee joint? Why?
25. Can a tee weld be strong if the welds on both sides do not have deep penetration? Why or why not?

Chapter 5

Shielded Metal Arc Welding of Pipe

OBJECTIVES

After completing this chapter, the student should be able to

- discuss three general categories of pipe welds, including how they are used and what type of weld root penetration and strength they require.
- compare pipe to tubing.
- discuss the advantages of welded pipe.
- discuss the preparation needed before welding pipe.
- explain the importance of not having arc strikes outside of the weld groove on pipe welds.
- explain the purpose of a hot pass.
- describe the purpose of the root, filler, and cover passes for a pipe weld.
- name advantages of the horizontal rolled pipe position.
- describe the vertical fixed position and advantages and disadvantages.
- discuss how to make a weld in the horizontal fixed position.
- describe the 45° fixed inclined position.

KEY TERMS

concave root surface
fixed inclined position
horizontal fixed pipe position
horizontal rolled pipe position
icicles
land
pipe
pressure range
root face
root gap
root suck-back
tubing
vertical fixed pipe position
welding uphill or downhill

INTRODUCTION

The pipe welder is considered by some other welders to be one of the most skilled welders in the industry. Often pipe welders have a great deal of pride. Some finished welded piping systems are considered works of art. Mastering the skills required to be a master pipe welder often takes a large commitment on the part of the welding student, but this commitment is well rewarded by the industry. The rewards of being a quality pipe welder include earning

better pay, working with the best equipment, and often having a helper to do the less glamorous jobs of cleanup and setup.

The shielded metal arc welding process is very well suited to the fabrication and repair of piping systems. Welded steel pipe is used in factories, power plants, refineries, and buildings to carry liquids and gases for a variety of purposes, **Figure 5-1**. Pipe is used to carry materials such as water, steam, chemicals, gases, petroleum, radioactive materials, and many others. Oil and gas are distributed through cross-country piping systems all over the United States, from Texas, California, Maine, and the northern slopes of Alaska. Welded pipe is used throughout ships, planes, and spacecraft to carry liquids such as fuels and hydraulic fluids. Pipe and tubing are also used for structures such as handrails, columns in buildings, light posts, and bicycle and motorcycle frames, as well as many other items we come in contact with each day.

The purpose for which pipe will be used largely determines how it is welded. This text groups pipe welds into the following three general categories:

Larry Jeffus

FIGURE 5-1 Refineries use miles of welded pipe.

- Low-pressure or light structural service
- Medium-pressure or medium structural service
- High-pressure or heavy structural service

Low-pressure or light structural piping Low-pressure piping systems that are considered noncritical may be used to carry water, noncorrosive or noncombustible chemicals, and other nonhazardous materials used in industry. These types of light structural piping assemblies are found on structural items such as handrails, truck racks, and other light-duty products. These pipe joints must be free from defects such as pinholes, undercut, slag inclusions, or any other defect that may cause the joints to leak or break prematurely. The weld does not require 100% penetration, although penetration should be uniform. Much of the strength of these pipe joints comes from the reinforcement. These welds should always be located so that they are easily repairable if necessary.

THINK GREEN

Reduce Grinding to Save Time, Resources, and Energy

You can save time, resources, and energy when E7018 electrodes are used for the entire weld because you can eliminate the need to grind the E6010 or E6011 root pass. Grinding the root pass can be time-consuming, require one or more grinding disks, and waste a lot of electrical power.

Medium-pressure piping Medium-pressure piping is used for low-pressure steam heat, corrosive or flammable chemicals, waste disposal, ship plumbing, and medium-service to heavy-service structural items such as highway signs, railings or light posts, trailer axles, and equipment frames or stands. These pipe joints must withstand heavy loads, but their failure will not be disastrous. Much of their strength is due to weld reinforcement, but there should be 100% root penetration around most of the joint. Often the root pass has been welded with E6010 or E6011 electrodes, and the other passes were welded with E7018 electrodes. But changes in the E7018 fluxes have enabled them to be used on the open root pass, so it is now common to make all of the weld passes with E7018.

High-pressure or heavy structural piping High-pressure piping systems are used for critical applications such as high-pressure steam, radioactive materials, the Alaskan pipeline, fired or unfired boilers, and refinery reactor lines. These types of heavy structural assemblies are used for aircraft airframes, offshore oil-rig jackets (legs), motorcycle frames, race car roll cages, truck axles, and several other critical, heavy-duty applications. The welds on both high-pressure piping systems and heavy structural

applications are considered critical. Their failure could result in a catastrophic event and possibly loss of life, so the welds must be as strong or stronger than the pipe itself. Often, the pipe used for these applications is extra heavy-duty pipe, with heavier wall thicknesses. The weld must have 100% root penetration over 100% of the joint. Root, filler, and reinforcement weld passes are made with an E7018 or stronger electrode. The welds are usually tested, and defects are repaired.

PIPE AND TUBING

Although **pipe** and **tubing** are similar in some aspects, they have different types of specifications and uses. They are only sometimes interchangeable. Pipe and tubing are both available as welded (seamed) or extruded (seamless).

In this chapter, the term ***pipe*** refers to pipe only. However, it should be understood that the welding sequence, procedures, and skills can also be used on thick-wall round tubing.

Pipe Specifications

The specifications for pipe sizes are given as the inside diameter for pipe that is 12 in. (305 mm) in diameter or smaller, and as the outside diameter for pipe larger than 12 in. (305 mm) in diameter. Tubing sizes are always given as the outside diameter. The desired shape of tubing, such as square, round, or rectangular, must also be listed with the ordering information, **Figure 5-2**.

Pipe strength Pipe strength is given as a schedule. Schedules 10 through 180 are available; schedule 40 is often considered a standard strength.

Tubing Specifications

The wall thickness of tubing is measured in inches (millimeters) or as U.S. standard sheet metal gauge thickness. The wall thickness for pipe is determined by its schedule, or **pressure range**. The larger the diameter of the pipe, the greater its area. As the area increases, so must

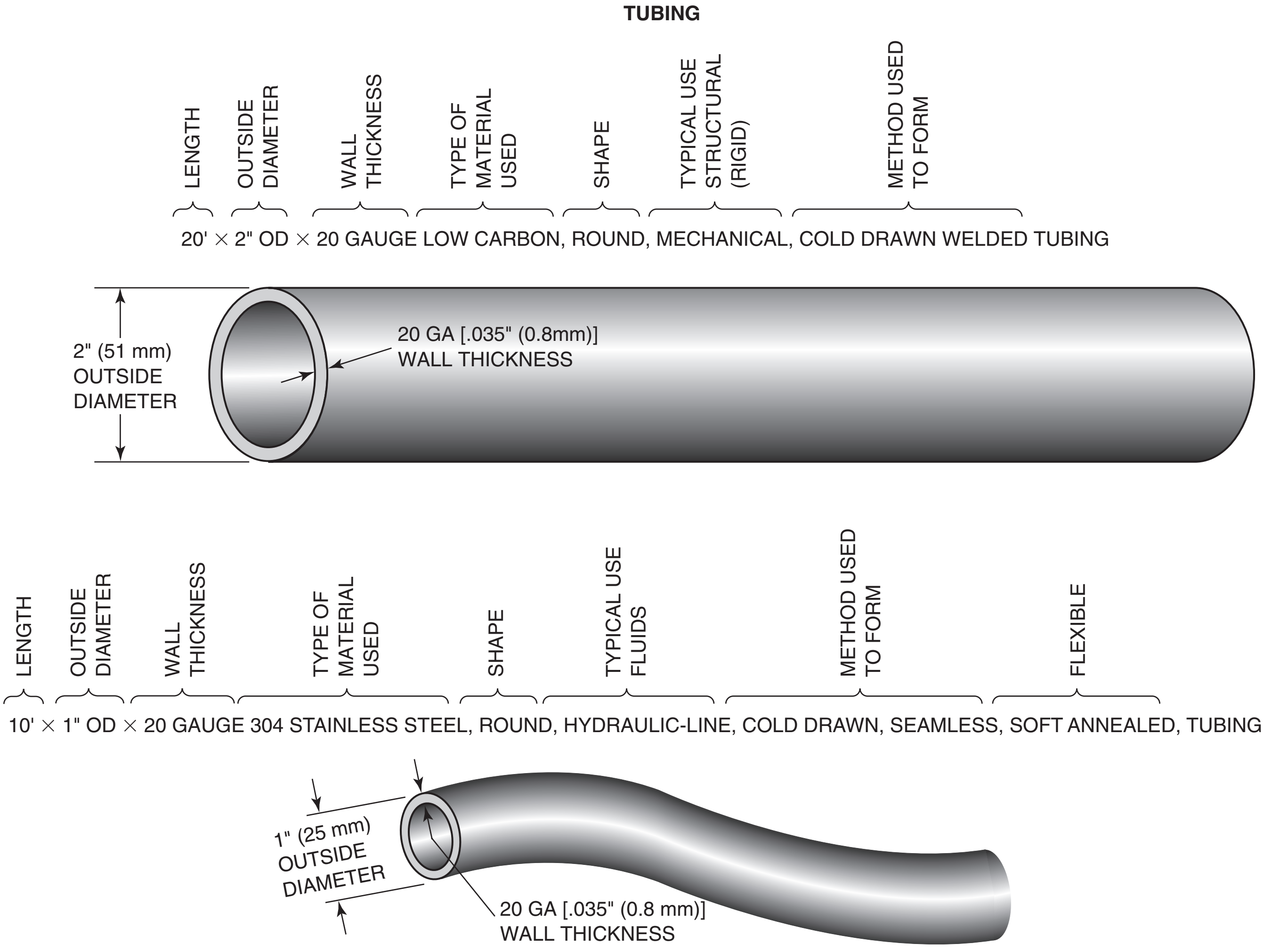

FIGURE 5-2 Typical specifications used when ordering tubing.

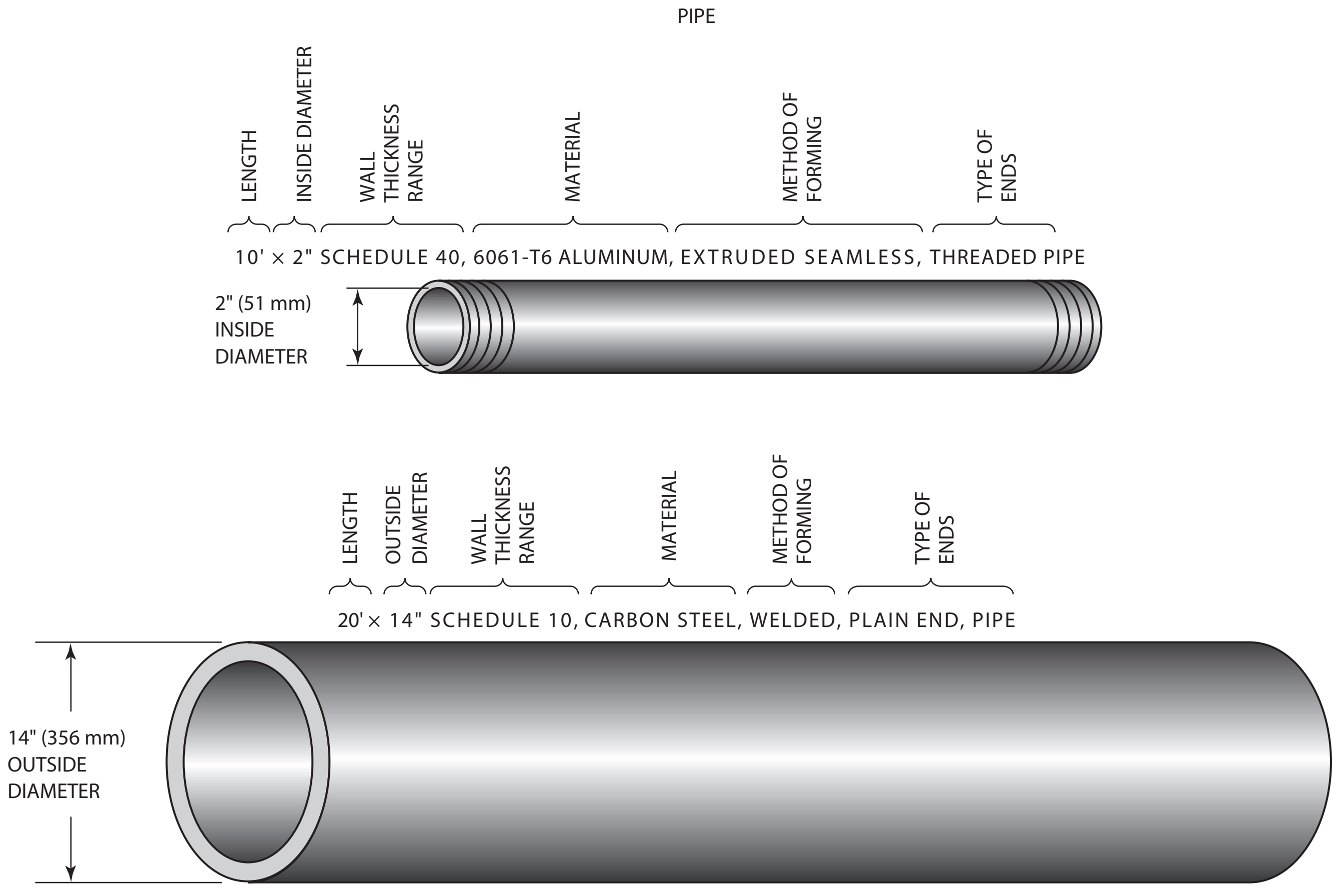

FIGURE 5-3 Typical specifications used when ordering pipe.

the wall thickness for the wall to withstand the same pressure range, **Figure 5-3**.

Tubing strength Tubing strength is the ability of tubing to withstand compression, bending, or twisting loads. Tubing should also be specified as rigid or flexible.

Pipe Applications

Most pipe that will be welded into a system is used to carry liquids or gases from one place to another. These systems may be designed to carry large or small quantities or materials with a wide range of pressures. Small diameter pipe may be used for some structural applications, but usually only on a limited scale.

Tubing Applications

Small diameter flexible tubing is commonly used to carry pressurized liquids or gases. Ridged tubing is normally used for structural applications. Some tubing is designed for specific purposes, such as electrical mechanical tubing (EMT), which is used to protect electrical wiring. Tubing can be used to replace some standard structural shapes such as I beams, channels, and angles for buildings. Tubing is also available in sizes that will slide one inside the other to be used in places where telescoping tubing is required, **Figure 5-4**.

ADVANTAGES OF WELDED PIPE

Most pipe 1 1/2 in. (38 mm) in diameter and all steel pipe 2 in. (51 mm) and larger are generally welded. Welded piping systems, compared to pipe joined by any other method, are stronger, require less maintenance, last for longer periods of time, allow smoother flow, and weigh less.

Strength

The thickness of the pipe and fitting is the same when they are welded together. Threaded pipe is weakened because the threads reduce the wall thickness of the pipe, **Figure 5-5**.

Less Maintenance Required

Over much time and use, welded pipe joints are resistant to leaks.

FIGURE 5-4 Space shuttle launch tower is constructed using round and rectangular tubing.

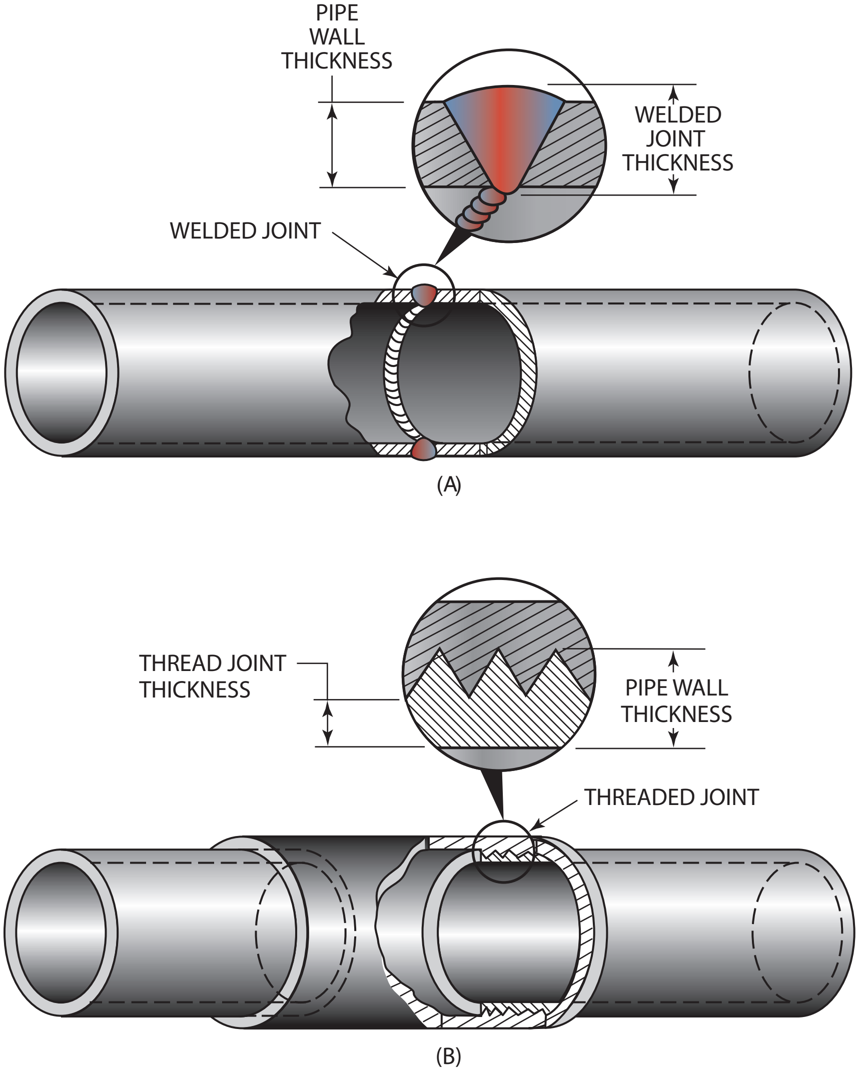

FIGURE 5-5 The welded joint (A) is thicker than the original pipe. The threaded joint (B) is thinner than the original pipe.

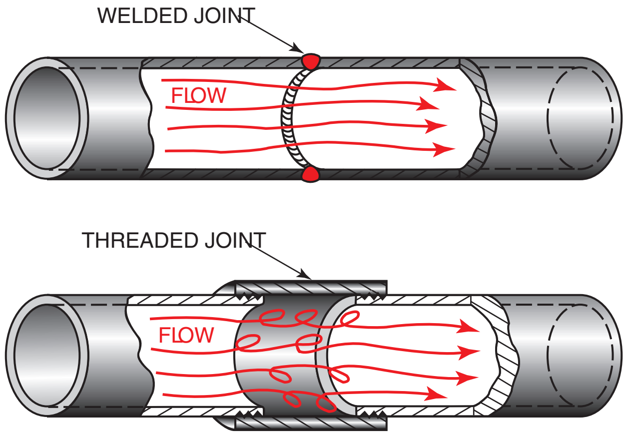

FIGURE 5-6 The flow along a welded pipe is less turbulent than that in a threaded pipe.

Longer Lasting

Welded pipe joints resist corrosion caused by electrochemical reactions because all the parts are made of the same types of metal. Small cracks between the threads on threaded pipe are likely spots for corrosion to start.

Smoother Flow

The inside of a welded fitting is the same size as the pipe itself. As material flows through the pipe, less turbulence is caused by unequal diameters, **Figure 5-6**. Large piping systems may be several miles in length. Lowered resistance to product flow can save on operating energy costs.

Lighter Weight

Threaded fittings are larger and weigh more than welded fittings and joints. The weight savings when welded joints are used for an aircraft means that it can fly longer and faster and can carry a larger load for less money. Buildings and factories will also realize a savings because welded joints are less expensive.

Other advantages of welded pipe include the following:

- Specially angled fittings can be made by cutting existing fittings, **Figure 5-7**.

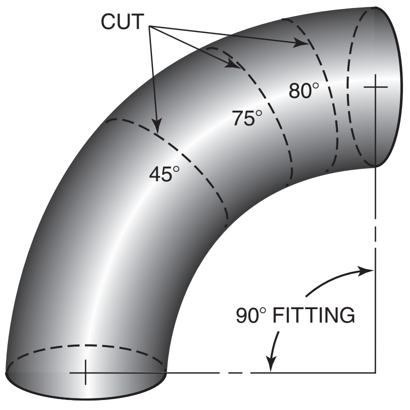

FIGURE 5-7 A standard 90° fitting can be cut to any special angle that is needed.

- Odd-shaped parts can be fabricated.
- A lot of highly specialized equipment is not required for each different size of pipe.
- Alignment of parts is easier. It is not necessary to overtighten or undertighten fittings so that they will line up.
- Removing, replacing, or changing parts is easy because special connections are not needed to remove the parts.

PREPARATION AND FIT-UP

The ends of pipe must be beveled for maximum penetration and high joint strength. The end can be beveled by flame cutting, machining, grinding, or a combination process. It is important that the bevel is at the correct angle, approximately 37 1/2° depending on specifications, and that the end meets squarely with the mating pipe. The sharp or feathered inner edge of the bevel should be ground flat, forming a chamfer. This area is called a **root face** or **land**. Final shaping should be done with a grinder so that the **root gap** will be uniform.

The bevel on the end of the pipe can be machine cut using a portable pipe beveling machine, **Figure 5-8**, or a handheld torch. Chapter 7 describes how to set up and operate flame-cutting equipment. A turntable, similar to the one shown in

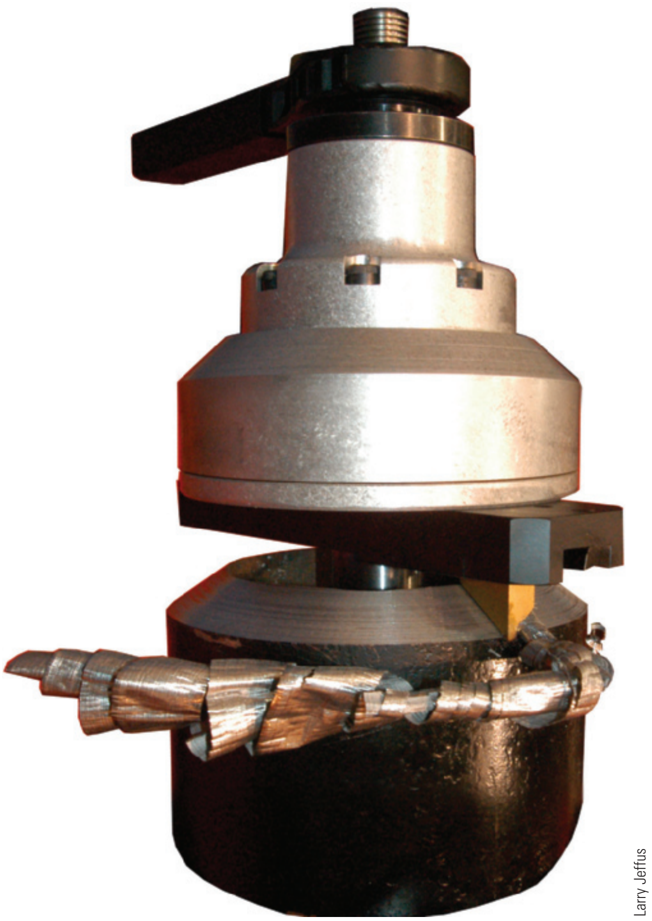

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FIGURE 5-8 Pipe beveling machine.

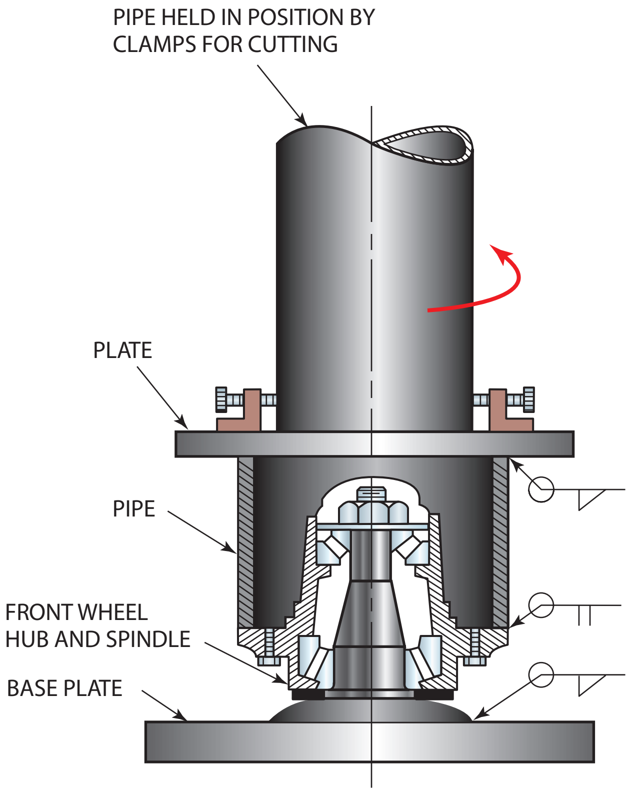

FIGURE 5-9 Turntable built from a front wheel assembly.

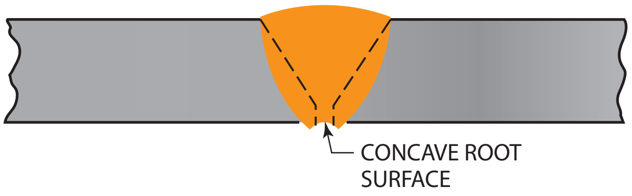

FIGURE 5-11 Root surface concavity.

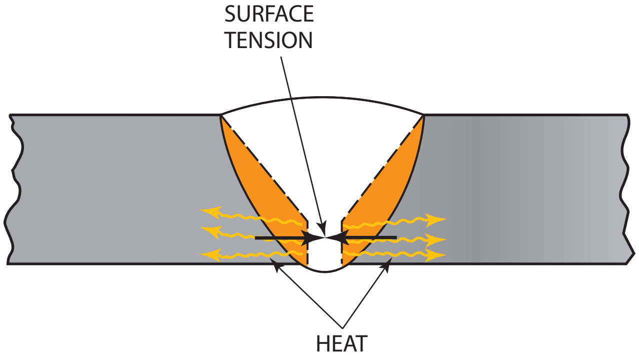

FIGURE 5-12 Heat is drawn out of the molten weld pool, and surface tension holds the pool in place.

Figure 5-9, can be made in the school shop and used for beveling short pieces of pipe. The turntable can be used vertically or horizontally. By turning the table slowly with the pipe held between the clamps, a hand torch can be used to produce smooth pipe bevels. Large-production welding shops may also use machines designed specifically for beveling pipe. These machines will accurately cut a 37 1/2° angle on the pipe.

The 37 1/2° angle allows easy access for the electrode with a minimum amount of filler metal required to fill the groove, **Figure 5-10**.

The root face will help a welder control both penetration and root suck-back. Penetration control is improved because there is more metal near the edge to absorb excessive arc heat. This makes machine adjustments less critical by allowing the molten weld pool to be quickly cooled between each electrode movement. **Root suck-back** is caused by the surface tension of the molten metal trying to pull itself into a ball, forming a **concave root surface**, **Figure 5-11**. The root face allows a larger molten weld pool to be controlled, and because of the increased size of the molten weld pool, it is not so affected by surface tension, **Figure 5-12**.

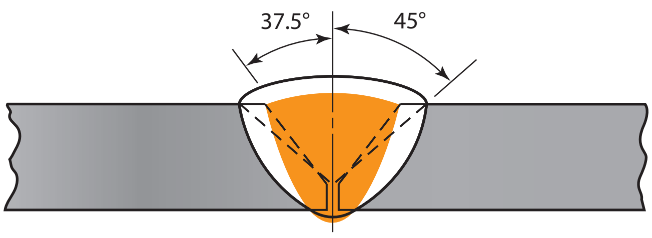

FIGURE 5-10 The 37 1/2° angled joint may use nearly 50% less filler metal, time, and heat as compared to the 45° angled joint.

THINK GREEN

Conserve Material

Welded piping systems use less metal than threaded piping systems do. In a threaded piping system a metal coupling or fitting is required, but the fitting is not required for welded systems. The environmental savings come from the reduced use of raw materials and the elimination of the production and transportation fuel costs of the fittings.

Fitting pipe together and holding it in place for welding become more difficult as the diameter of the pipe gets larger. Devices for clamping and holding pipe in place are available, or a series of wedges and dogs can be used, **Figure 5-13**. In the Practices for this chapter, the pieces of pipe the welder will be using are schedule 40 mild steel pipe 3 in. (76 mm) or larger in diameter and approximately 1 1/2 in. (38 mm) long. The short 1 1/2 in. (38 mm) lengths are easier to force into round alignment if needed. The maximum offset (high-low) for most piping codes is 1/8 in. (13 mm).

A welder can use a vise to hold the pipes in place for tack welding. If the pipe is not round and does not align properly, first tack weld the pipe together and then quickly hit the tack while holding the pipe over the horn on an anvil, **Figure 5-14**. This action will force the pipe into alignment. For pipe that is too distorted to be forced into

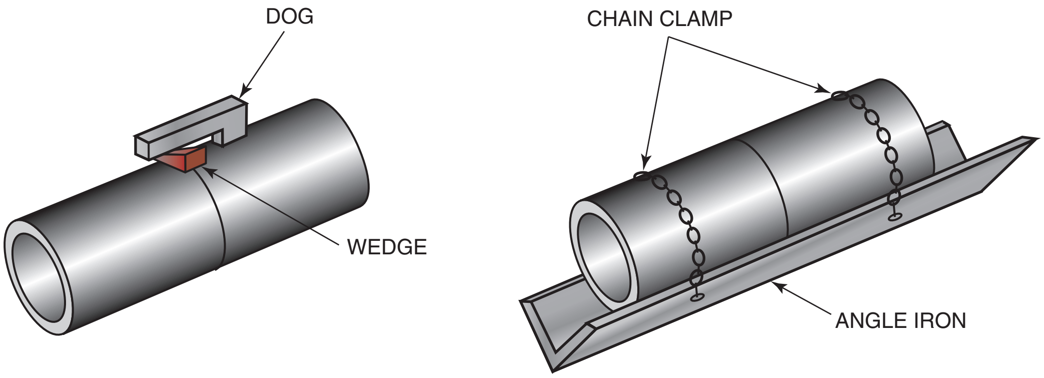

FIGURE 5-13 Shop fabrications used to align pipe joints.

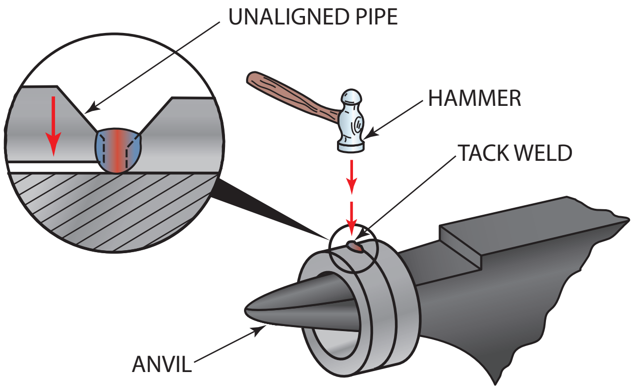

FIGURE 5-14 Hitting a hot tack weld can align a pipe joint.

alignment in this manner, a welder must grind down the high points to ensure a good fit.

PRACTICE WELDS

One of the major problems to be overcome in pipe welding is learning how to make the transition from one position to another. The rate of change in welding position is slower with large diameter pipes, but the large diameter pipes require more time to weld. When a welder first starts welding, a large diameter pipe should be used to make learning this transition easier. As welders develop skill and the technique of pipe welding, they can change to the small diameter pipe sizes. Pipe that is 3 in. (76 mm) can be welded quickly and it is large enough for the welder to be able to cut out specimens for testing.

Pipe sections used for these practice welds should be no shorter than 1 1/2 in. (38 mm). Pipe that is shorter than 1 1/2 in. (38 mm) rapidly becomes overheated, making welding more difficult.

To progress more quickly with pipe welds, a welder should master grooved plate welds. Once plate welding is mastered in all positions, pipe skills can be developed faster and easier.

Pipe welding is performed with either E6010 or E6011 electrodes for the complete weld, or these electrodes are used for the root pass, and E7018 electrodes are used to complete the joint. Pipe welding can also be done using the E7018 electrode for the entire weld, **Figure 5-15**.

The practice pieces of pipe used in the school shop are much shorter than the pieces of pipe used in industry. When learning to weld on short pipe, it is a good idea to avoid positioning oneself where longer pipe would eventually be located. Often it is easier to stand at the end of a pipe rather than to one side; however, this cannot be done if the weld is being made on a full length of pipe.

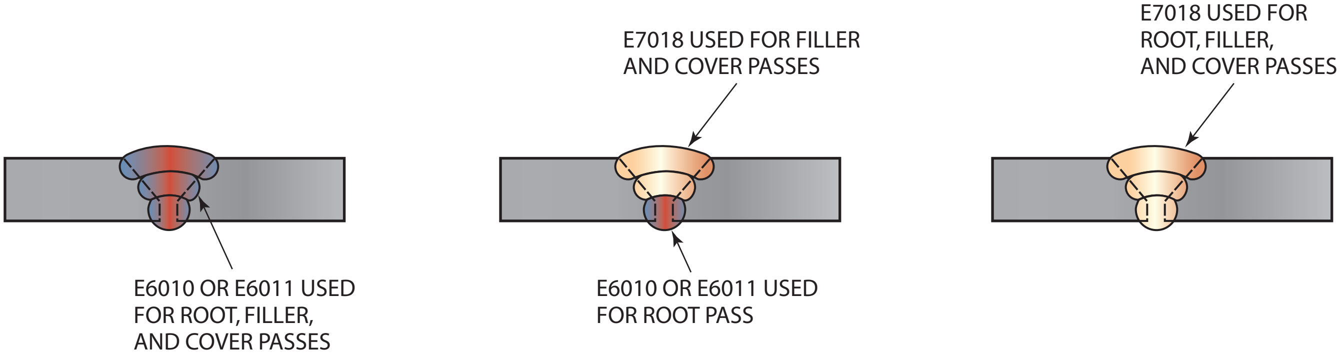

FIGURE 5-15 Single or multiple types of electrodes may be used when producing a pipe weld. The electrode selected is most often controlled by a code or specification.

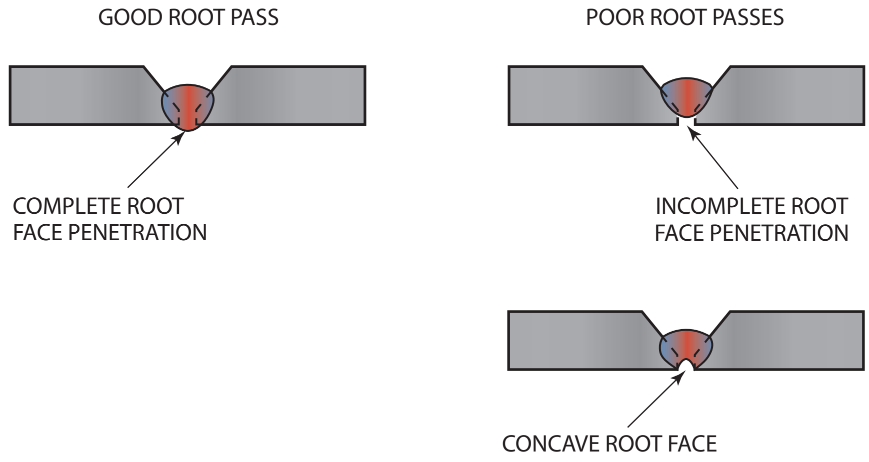

FIGURE 5-16 Root pass.

> **THINK GREEN**
> **Accurate Fit-up Equals Savings**
> Properly fitted pipe requires less welding and grinding time and less filler metal and grinding disks. Even slight changes in the groove angle, root spacing, or alignment can make a difference, but very poor fit-up can result in the finished weld costing several times more than that of a properly fitted joint.

WELD STANDARDS

Weld quality is very important to the pipe welding industry. Like other welds, the major parts of the weld come under a higher level of inspection. However, the surface of the pipe on both sides of the weld is also important. No arc strikes should be made on this surface. Arc strikes outside of the weld groove are considered to be defects by much of the pipe welding industry. Arc strikes form small hardness spots that, if not remelted by the weld, will crack as the pipe expands and contracts with heat and pressure changes. Thus, they are a defect and must be removed and the area repaired. This removal under some standards may simply involve grinding them off, but under some codes they must be treated like any other defect, and a special weld repair procedure must be followed. Because of the importance of not having arc strikes outside the weld groove on pipe welds, you should try to avoid them from the beginning. In Chapter 4, Practice 4-3, several techniques are described to avoid arc strikes outside of the welding zone. You may want to refer back to this section if you have difficulty in making arc starts accurately.

WELD PASSES

All pipe welds are made up of a series of individual weld passes. The different types of weld passes needed to make a pipe weld are almost always the same, root weld pass, hot weld pass, filler weld pass(es), and cover weld pass(es). However, the number of passes required to complete a pipe weld is dependent on the pipe's wall thickness.

Root Weld Pass

A root weld is the first weld in a joint, **Figure 5-16**. It is part of a series of welds that make up a multiple pass weld. The root weld is used to establish the contour and depth of penetration. The most important part of a root weld is the internal root face or, in the case of pipe, the inside surface.

Root face The root face is the part of this weld pass that must be smooth and uniform, **Figure 5-17**. Imperfections on the root face can cause a number of problems for the pipe once it has been put in service. Incomplete fusion or under-fill will reduce the pipe's ability to withstand the force that a good root weld joint could. In addition, the lack of fusion can leave a crack that can collect material that can start crevice corrosion. It also can become a

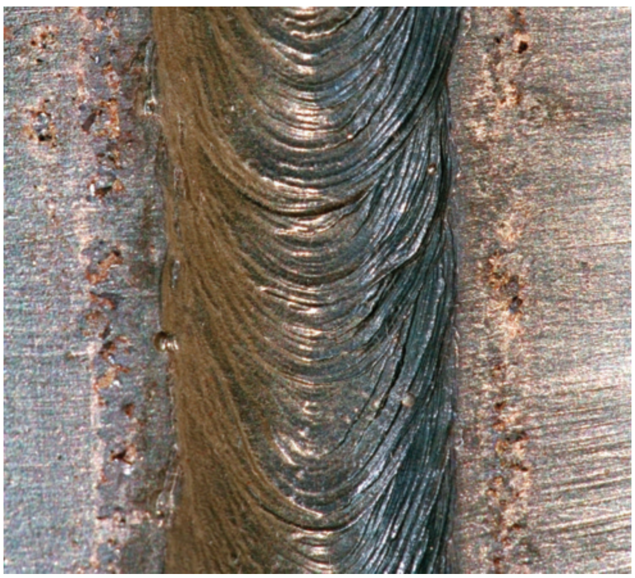

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FIGURE 5-17 The root face must be uniform.

stress point where a crack can start, causing the pipe to fail. Excessive root buildup or **icicles** can cause turbulence in the fluids flowing, resulting in erosion corrosion alongside the weld.

On some piping systems, consumable inserts or backing rings are used to control penetration and the inside contour. Most pipe welds are made without these devices to control penetration.

Weld face Do not concentrate on the appearance of the root face because it can be cleaned or reshaped by grinding if needed. A grinder with a narrow grinding disk can be used to repair the face of the root pass. The grinding removes slag along the sides of the weld bead and makes it easier to add the next pass. Not all root passes are ground. Pipe that is to be used in low-pressure and medium-pressure systems is not usually ground. Grinding each root pass takes extra time and does not give the welder the experience of using a hot pass. Most slag must be completely removed by chipping and wire brushing before the hot pass is used.

An area that has less than 100% root penetration can have the root weld ground down enough so that the hot pass can easily push the penetration all the way through.

If you need more experience or practice in making an open root weld, refer to Chapter 4.

Hot Weld Pass

The hot pass is used to quickly burn out small amounts of slag trapped along the edge of the root pass. This is slag that cannot be removed easily by chipping or wire brushing. The hot pass can also be used to reshape the root pass by using high current settings and a faster-than-normal travel speed.

Slag is mostly composed of silicon dioxide, which melts at approximately 3100°F (1705°C). Steel melts at approximately 2600°F (1440°C). Because the slag has a melting temperature more than 500°F (270°C) hotter than the surrounding metal, the weld has to melt the metal trapping the slag so it can float free. A high current will quickly melt enough surface to allow the slag to float free; a fast travel speed will prevent burnthrough. The fast travel speed forms a concave weld bead that is easy to clean for the welds that will follow.

Filler Weld Pass

After thoroughly removing slag from the weld groove by chipping, wire brushing, or grinding, it is ready to be filled. The filler pass(es) may be either a series of stringer beads, **Figure 5-18**, or a weave bead, **Figure 5-19**. Stringer beads require less welder skill because of the small amount of metal that is molten at one time.

The weld bead crater must be cleaned before the next electrode is started. Failure to clean the crater will result in slag inclusions. On high-strength, high-pressure

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FIGURE 5-18 Filler pass using stringer beads.

ELECTRODE DIAMETER	BEAD WIDTH
$\frac{1}{8}$" (3 mm)	$\frac{1}{4}$" (6 mm)
$\frac{5}{32}$" (4 mm)	$\frac{5}{16}$" (8 mm)
$\frac{3}{16}$" (4.8 mm)	$\frac{3}{8}$" (10 mm)

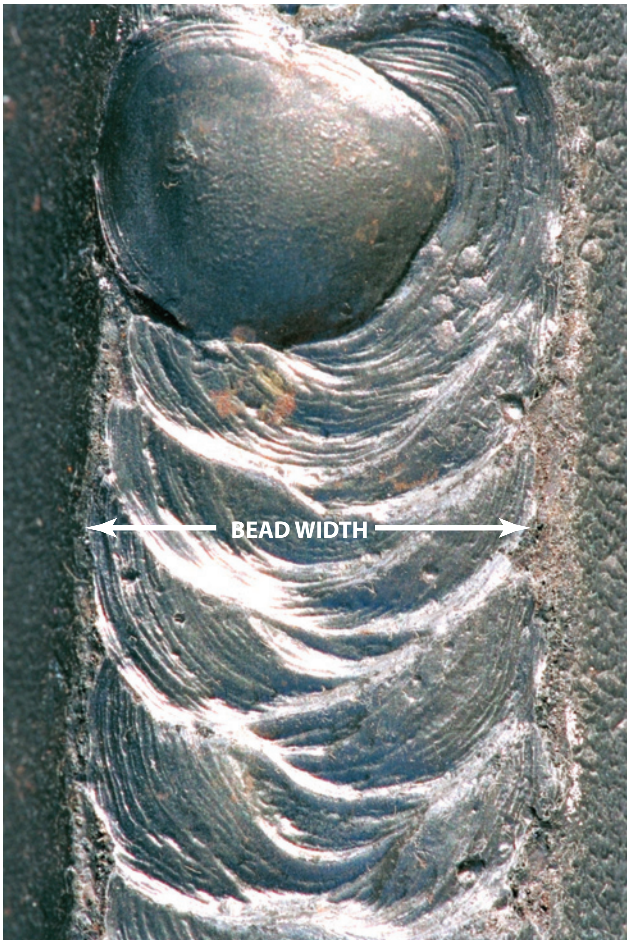

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FIGURE 5-19 Filler pass using weave bead. The bead width should not be more than two times the rod diameter.

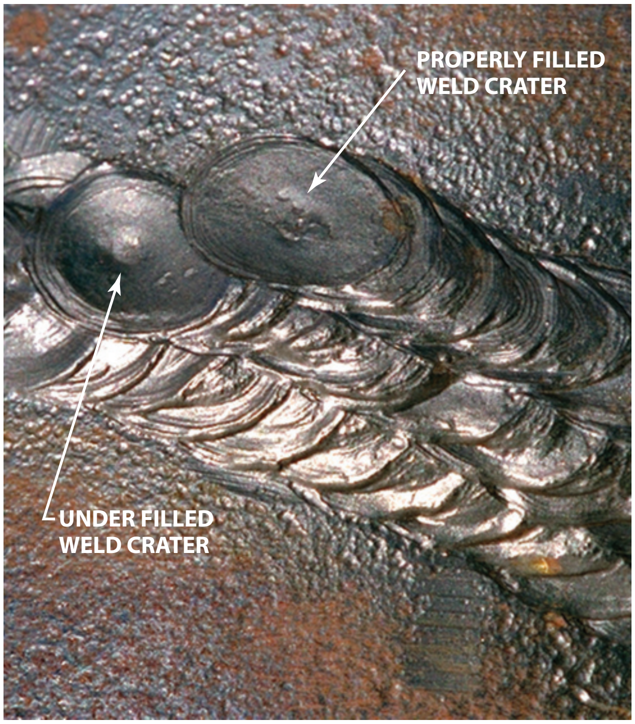


FIGURE 5-20 The weld crater should be filled to prevent cracking and cleaned of slag before restarting the arc.

pipe welds, the crater should be slightly ground to ensure its cleanliness, **Figure 5-20**. When the bead has gone completely around the pipe, it should continue past the starting point so that good fusion is ensured, **Figure 5-21**. The locations of starting and stopping spots for each weld pass must be staggered. The weld groove should be filled level with these beads so that it is ready for the cover pass.

FIGURE 5-21 Avoid starting and stopping all weld passes in the same area.

Cover Weld Pass

The final covering on a weld is referred to as the cover pass or cap. It may be a weave or stringer bead. The cover pass should not be too wide or have too much reinforcement, **Figure 5-22**. Cover passes that are excessively large will reduce the pipe's strength, not increase it. A large cover pass will cause the stresses in the pipe to be concentrated at the sides of the weld. An oversized weld will not allow the pipe to expand and contract uniformly along its length. This concentration is similar to the restriction a rubber band would have on an inflated balloon if it were put around its center.

The cover pass should be kept as uniform and as neat as possible, **Figure 5-23**. A visual checking is often all that low-pressure and medium-pressure welds receive, and a nice-looking cover will pass a visual inspection every time.

1G HORIZONTAL ROLLED POSITION

The **horizontal rolled pipe position** is commonly used in fabrication shops where structures or small systems can be positioned for the convenience of the welder, **Figure 5-24**. The consistent high quality and quantity of welds produced in this position make it very desirable for both the welder and the company.

The penetration and buildup of the weld are controlled more easily with the pipe in this position. Weld visibility and welder comfort are improved so that welder fatigue is less of a problem. The pipe can be rolled continuously with some types of positioners, and the weld can be made in one continuous bead.

Because of the ease in welding and the level of skill required, welders who are certified in this position may not be qualified to make welds in other positions.

PRACTICE 5-1

Beading, 1G Position, Using E6010 or E6011 Electrodes and E7018 Electrodes

Using a properly set up and adjusted arc welding machine, proper safety protection, E6010 or E6011 and E7018 arc welding electrodes with a 1/8 in. (3 mm) diameter, and schedule 40 mild steel pipe 3 in. (76 mm) or larger in diameter, you will make a straight stringer bead around a horizontally rolled pipe.

Place the pipe horizontally on the welding table in a vee block made of angle iron, **Figure 5-25**. The vee block will hold the pipe steady and allow it to be moved easily

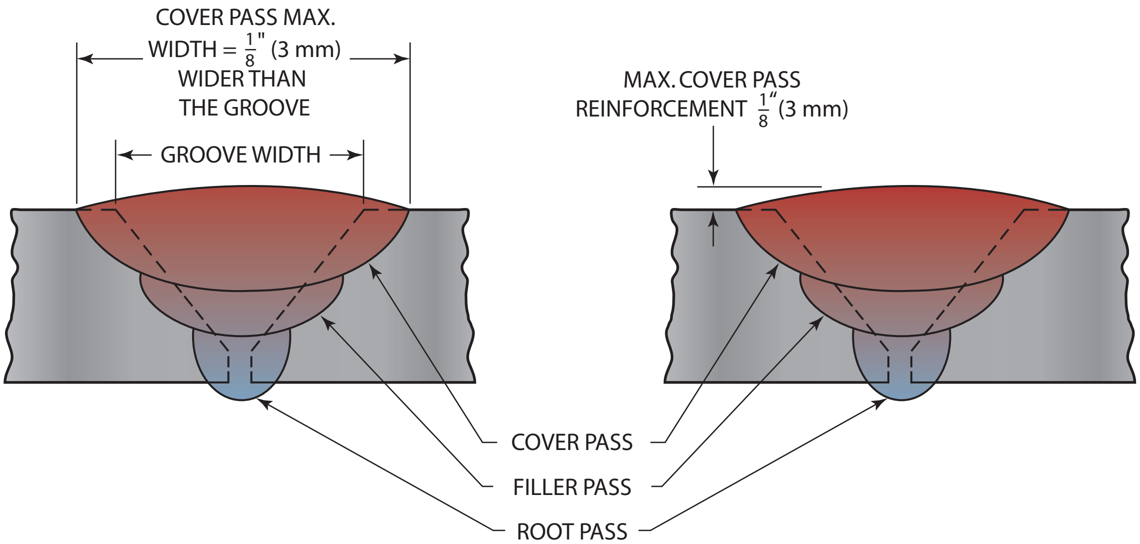


FIGURE 5-22 Excessively wide or built-up welds restrict pipe expansion at the joint, which may cause premature failure. Check the appropriate code or standard for exact specifications.

FIGURE 5-23 Uniformity in each pass shows a high degree of welder skill and increases the probability that the weld will pass testing.

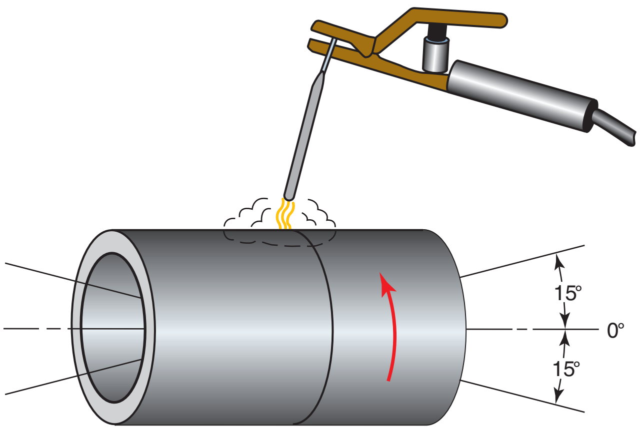


FIGURE 5-24 1G position. The pipe is rolled horizontally.

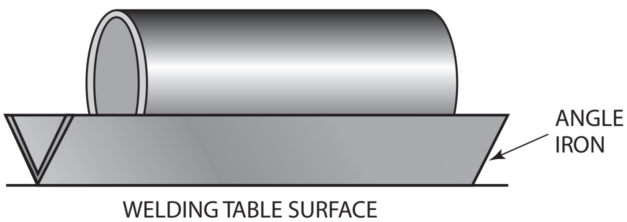


FIGURE 5-25 Angle iron pipe support.

between each bead. Strike an arc on the pipe at the 11 o'clock position. Make a stringer bead over the 12 o'clock position, stopping at the 1 o'clock position, **Figure 5-26**. Roll the pipe until the end of the weld is at the 11 o'clock position. Clean the weld crater by chipping and wire brushing.

Strike the arc again and establish a molten weld pool at the leading edge of the weld crater. With the molten weld pool reestablished, move the electrode back on the weld bead just short of the last full ripple, **Figure 5-27**. This action will both reestablish good fusion and keep the weld bead size uniform. Now that the new weld bead is tied into the old weld, continue welding to the 1 o'clock position again. Stop welding, roll the pipe, clean the crater, and resume welding. Keep repeating this procedure until the weld is completely around the pipe. Before the last weld is started, clean the end of the first weld so that the end and beginning beads can be tied together smoothly. When you reach the beginning bead, swing your electrode around on both sides of the weld bead. A poor beginning of a weld bead is always high and narrow and has little penetration, **Figure 5-28**. By swinging the weave pattern (the "C" pattern is best) on both sides of the bead, you can make the

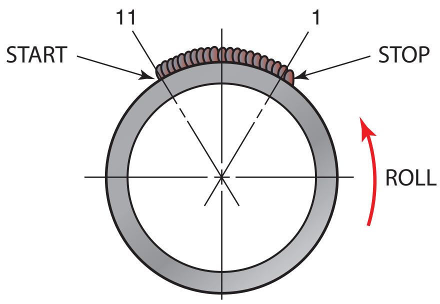


FIGURE 5-26 1G pipe welding area.

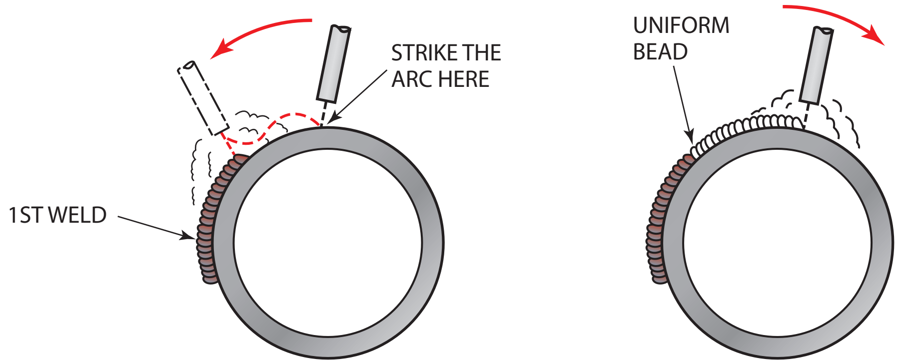


FIGURE 5-27 Keeping the weld uniform is important when restarting the arc.

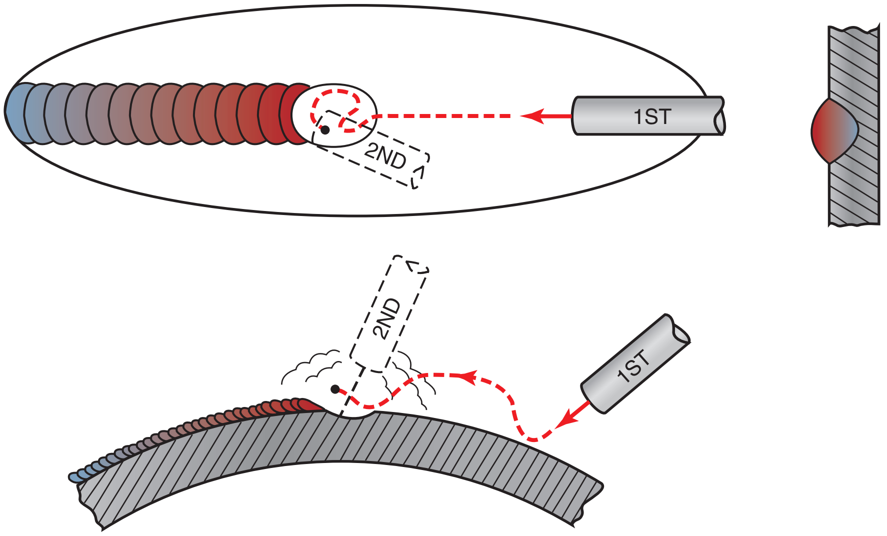


FIGURE 5-28 Restarting the weld.

bead correctly so that the width is uniform. The added heat will give deeper penetration at the starting point. Hold the arc in the crater for a moment until it is built up, but do not overfill the crater.

Cool, chip, and inspect the bead for defects. Repeat the beads as needed until they are mastered. Turn off the welding machine and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 5-2

Butt Joint, 1G Position, Using E6010 or E6011 Electrodes

Using a properly set up and adjusted arc welding machine, proper safety protection, E6010 or E6011 arc welding electrodes with a 1/8 in. (3 mm) diameter, and two or more pieces of schedule 40 mild steel pipe 3 in. (76 mm) or larger in diameter, you will make a pipe butt joint in the 1G horizontal rolled position, **Figure 5-29**.

Tack weld two pieces of pipe together as shown in **Figure 5-30**. Place the pipe horizontally in a vee block on the welding table. Start the root pass at the 11 o'clock position using a very short arc with the rod's flux actually touching the sides of the weld groove. A higher current setting will help to force the root weld all the way through to the inside of the joint. To keep the weld from burning through you can travel faster and lower the welding current an amp or two. Weld toward the 1 o'clock position. Stop and roll the pipe, chip the slag, and repeat the weld until you have completed the root pass.

Clean the root pass by chipping and wire brushing. The root pass should not be ground this time. Replace the pipe in the vee block on the table so that the hot pass can be done. Turn up the machine amperage, enough to remelt the root weld surface, for the hot pass. Use a stepped electrode pattern, moving forward each time

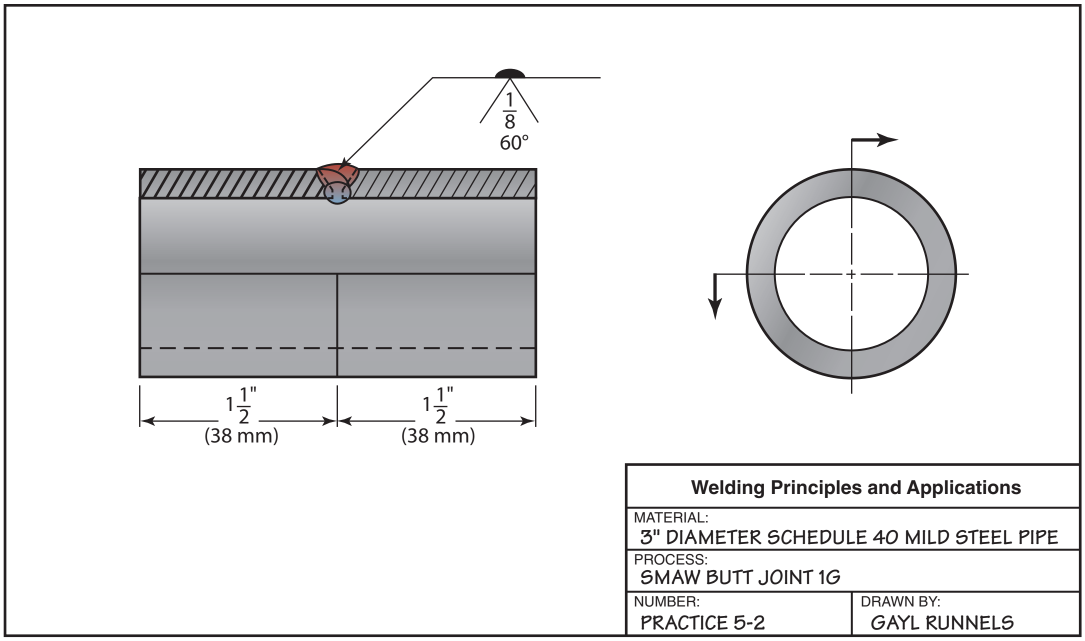


FIGURE 5-29 Butt joint in the 1G position.

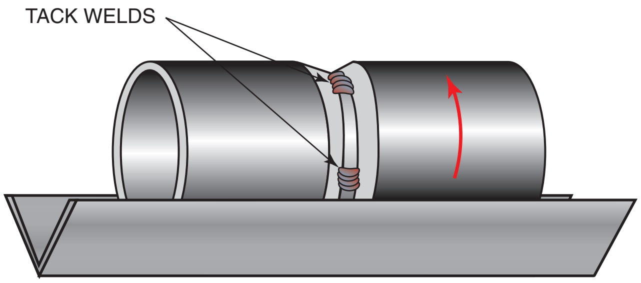


FIGURE 5-30 The tack welds are to be evenly spaced around the pipe. Use four tacks on small diameter pipe and six or more on large diameter pipe.

the molten weld pool washes out the slag, and returning each time the molten weld pool is nearly all solid, **Figure 5-31**. Weld from the 11 o'clock position to the 1 o'clock position before stopping, rolling, and chipping the weld. Repeat this procedure until the hot pass is complete.

The filler pass and cover pass may be the same pass on this joint. Turn down the machine amperage. Use a "T," "J," "C," or zigzag pattern for this weld. Start the weld at the 10 o'clock position and stop at the 12 o'clock position. Sweep the electrode so that the molten weld pool melts out any slag trapped by the hot pass. Watch the back edge

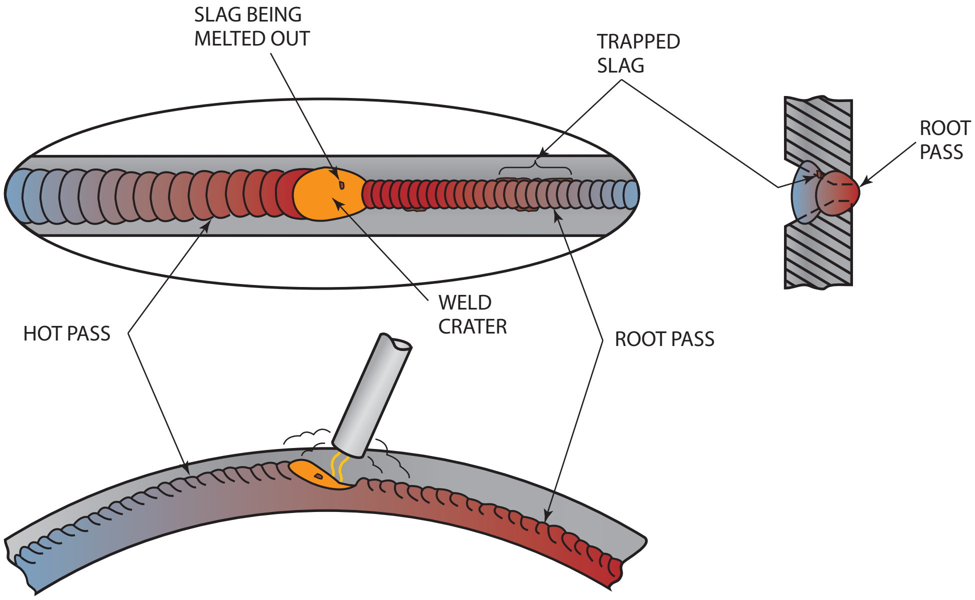


FIGURE 5-31 Hot pass.

of the bead to see that the molten weld pool is filling the groove completely. Turn, chip, and continue the bead until the weld is complete. Repeat this weld until you can consistently make welds free of defects. Turn off the welding machine and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 5-3

Butt Joint, 1G Position, Using E6010 or E6011 Electrodes for the Root Pass with E7018 Electrodes for the Filler and Cover Passes

Using the same setup, materials, and procedures as described in Practice 5-2, you will make a horizontal rolled butt joint in pipe, **Figure 5-32**. The root pass is to have 100% penetration over 80% or more of the length of the weld.

Set the pipe in the vee block on the welding table and make the root pass as explained in Practice 5-2. Watch for 100% penetration with no icicles. A hot pass or grinder can be used to clean the face of the root pass. Use an E7018 electrode for the filler and cover passes. The E7018 electrode should not be weaved more than 2 1/2 times the diameter of the electrode. Excessively wide weaving will allow the molten weld pool to become contaminated, **Figure 5-33**.

FIGURE 5-33 Weave beads more than 2 1/2 times the diameter of the electrode may be nice-looking, but the atmosphere may contaminate the unprotected part of the molten weld pool.

After the weld is completed, visually inspect it for 100% penetration around 80% of the root length. Check the weld for uniformity and visual defects on the cover pass. Repeat this weld until you can consistently make welds free of defects. Turn off the welding machine and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

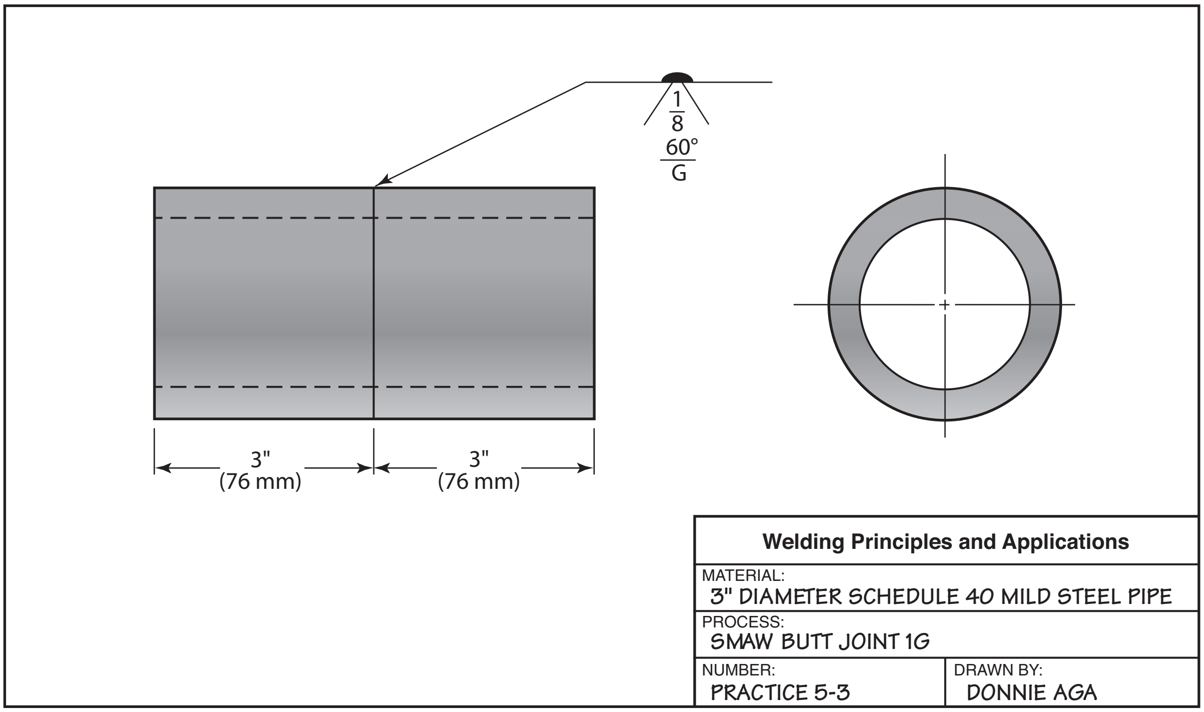


FIGURE 5-32 Butt joint in the 1G position to be tested.

AWS SENSE CERTIFICATION TEST 1G

Once you have mastered the 1G pipe groove weld you may want to take the AWS SENSE pipe welding certification test outlined in Chapter 6.

2G VERTICAL FIXED POSITION

In the 2G **vertical fixed pipe position**, the pipe is vertical and the weld is horizontal, **Figure 5-34**. With these welds, the welder does not need to change welding positions constantly. The major problem that faces welders when welding pipe in this position is that the area to be welded is often located in corners. Because of this location, reaching the back side of the weld is difficult. In the practices that follow, you may turn the pipe between welds. As a welder gains more experience, welds in tight places will become easier.

The welds must be completed in the correct sequence, **Figure 5-35**. The root pass goes in as with other joints. To reduce the sagging of the bottom of the weld, increase the electrode-to-work angle. As long as the weld is burned-in well and does not have cold lap on the bottom, the weld is correct. Each of the filler and cover welds that follow must be supported by the previous weld bead.

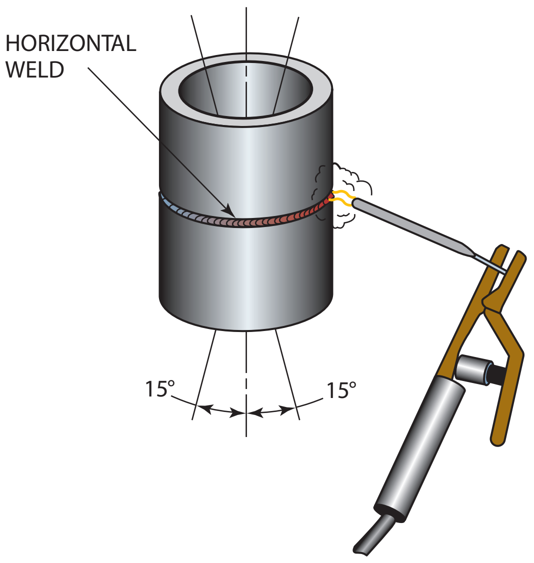


FIGURE 5-34 2G position. The pipe is fixed vertically, and the weld is made horizontally around it.

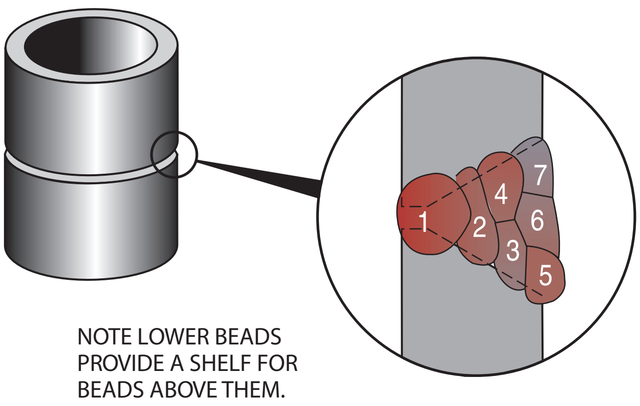


FIGURE 5-35 2G Pipe welding position.

PRACTICE 5-4

Stringer Bead, 2G Position, Using E6010 or E6011 Electrodes and E7018 Electrodes

Using the same setup, materials, and electrodes as listed in Practice 5-1, you will make straight stringer beads on a pipe that is in the vertical position.

The “J” weave pattern should be used so that the molten weld pool will be supported by the lower edge of the solidified metal, **Figure 5-36**. Keep the electrode at an upward and trailing angle so the arc force will help to keep the weld in place.

Repeat these stringer beads as needed, with both groups of electrodes, until you can consistently make welds free of defects. Turn off the welding machine and clean your work area when you are finished welding.

Complete a copy of the “Student Welding Report” listed in Appendix I or provided by your instructor. ◆

PRACTICE 5-5

Butt Joint, 2G Position, Using E6010 or E6011 Electrodes

Using a properly set up and adjusted arc welding machine, proper safety protection, E6010 or E6011 arc welding electrodes with a 1/8 in. (3 mm) diameter, and two or more

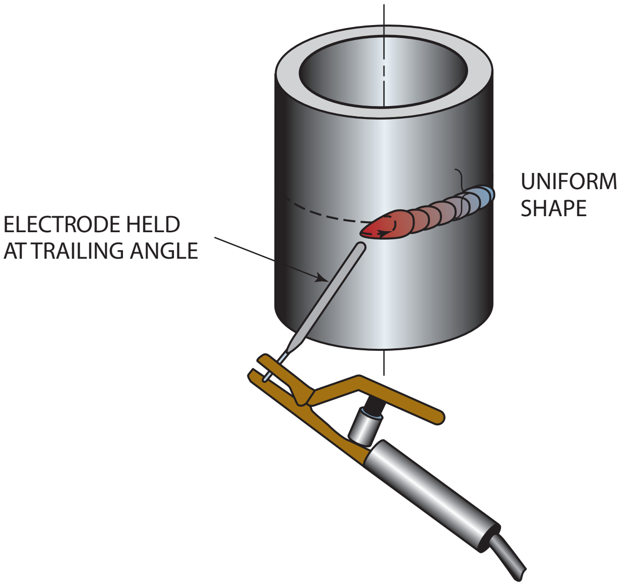


FIGURE 5-36 Electrode position and weave pattern for a weld on vertical pipe.

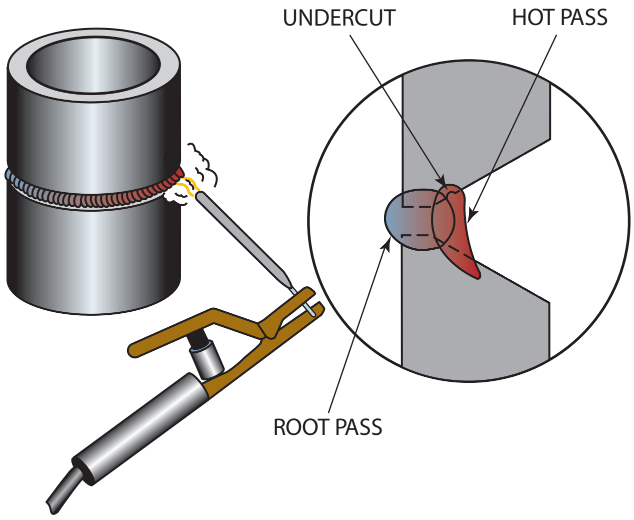


FIGURE 5-37 Hot pass.

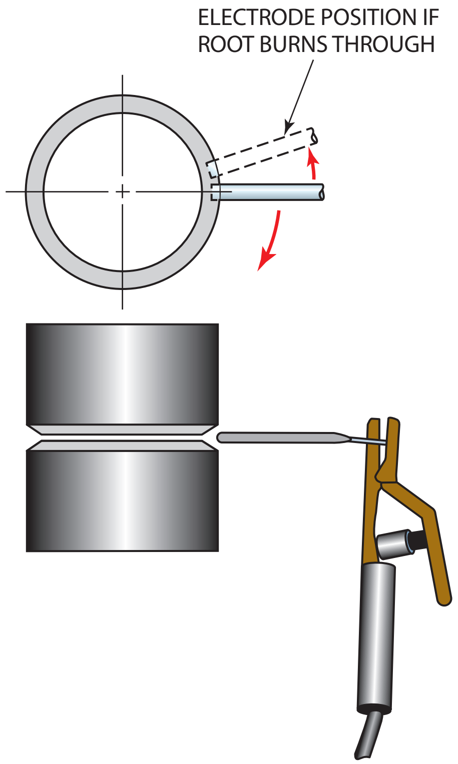


FIGURE 5-38 Electrode position and movement for the root pass.

pieces of schedule 40 mild steel pipe 3 in. (76 mm) or larger in diameter, you will make a butt joint on a pipe that is in the vertical position.

Place the pipe on the arc welding table. Strike an arc and make a root weld that is as long as possible. If the root gap is uniform, then a step pattern must be used. After completing and cleaning the root pass, make a hot pass. The hot pass need only burn the root pass clean, **Figure 5-37**. Undercut on the top pipe is acceptable.

The filler and cover passes should be stringer beads. By keeping the molten weld pool size small, control is easier. Cool, chip, and inspect the completed weld for uniformity and defects. Repeat this weld until you can consistently make welds free of defects. Turn off the welding machine and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 5-6

Butt Joint, 2G Position, Using E6010 or E6011 Electrodes for the Root Pass and E7018 Electrodes for the Filler and Cover Passes

Using the same setup, materials, and procedures as described in Practice 5-4, you will make a vertical fixed pipe weld. The root pass is to have 100% penetration over 80% or more of the length of the weld.

Place the pipe vertically on the welding table. Hold the electrode at a 90° angle to the pipe axis and with a slight trailing angle, **Figure 5-38**. The electrode should be held tightly into the joint. If a burnthrough occurs, quickly push the electrode back over the burnthrough while increasing the trailing angle. This action forces the weld metal back into the opening. When the root pass is complete, chip the surface slag and then clean out the trapped slag by grinding or chipping, or use a hot pass.

Use E7018 electrodes for the filler and cover passes with a stringer pattern. The weave beads are not recommended with this electrode and position because they tend to undercut the top and overlap the bottom edge. After the weld is completed, visually inspect it for 100% penetration around 80% of the root length. Check the weld for uniformity and visual defects on the cover pass. Repeat the weld until you can consistently make welds free of defects. Turn off the welding machine and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

AWS SENSE CERTIFICATION TEST 1G

Once you have mastered the 2G pipe groove weld you may want to take the AWS SENSE pipe welding certification test outlined in Chapter 6.

5G HORIZONTAL FIXED POSITION

The 5G **horizontal fixed pipe position** is the most often used pipe welding position. Welds produced in flat, vertical up or vertical down, and overhead positions must be uniform in appearance and of high quality.

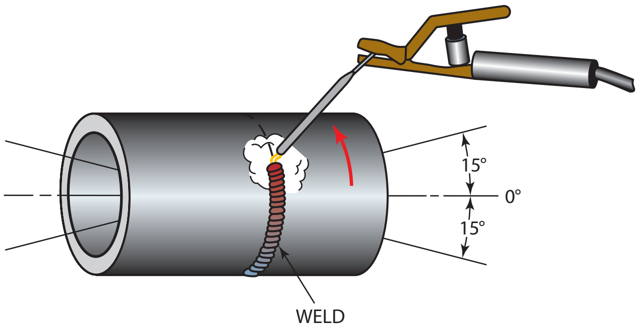


FIGURE 5-39 5G horizontal fixed position.

When practicing these welds, mark the top of the pipe for future reference. Moving the pipe will make welding easier, but the same side must stay on the top at all times, **Figure 5-39**.

The root pass can be performed by **welding uphill or downhill**. In industry, the method used to weld the root pass is determined by established weld procedures. If there are no procedures requiring a specific direction, then the choice is usually made based on fit-up. A close parallel root opening can be welded uphill or downhill. A root opening that is wide or uneven must be welded uphill. In the following Practices, the welder can make the choice of direction, but both directions should be tried.

The pipe may be removed from the welding position for chipping, wire brushing, or grinding. The pipe can be held in place by welding a piece of flat stock to it and clamping the flat stock to a pipe stand, **Figure 5-40**.

The electrode angle should always be upward, **Figure 5-41**. Changing the angle toward the top and bottom will help control the bead shape. The bead, if welded downhill, should start before the 12 o'clock position and continue past the 6 o'clock position to ensure good fusion and tie-in of the welds. The arc must always be struck inside the joint preparation groove.

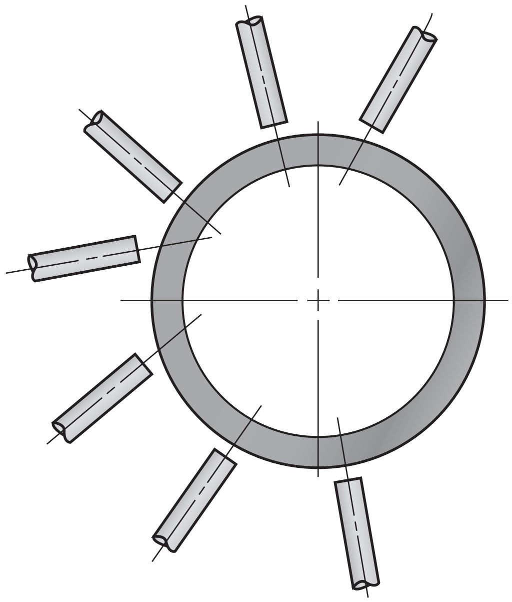


FIGURE 5-41 Electrode angle.

PRACTICE 5-7

Stringer Bead, 5G Position, Using E6010 or E6011 Electrodes and E7018 Electrodes

Using the same setup, materials, and electrodes as listed in Practice 5-1, you will make straight stringer beads in the horizontal fixed 5G position using both groups of electrodes.

Clamp the pipe horizontally between waist and chest level. Starting at the 11 o'clock position, make a downhill straight stringer bead through the 12 o'clock and 6 o'clock positions. Stop at the 7 o'clock position, **Figure 5-42**. Using a new electrode, start at the 5 o'clock position and make an uphill straight stringer bead through the 6 o'clock and 12 o'clock positions. Stop at the 1 o'clock

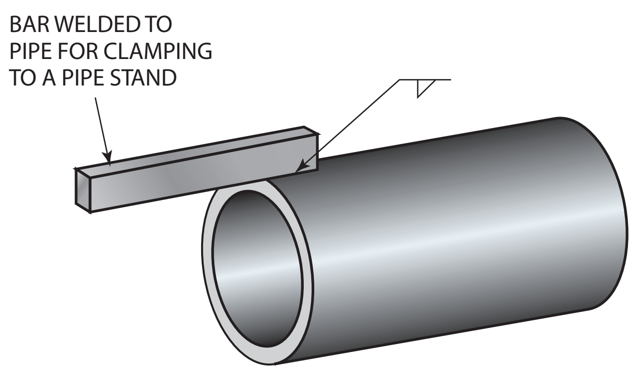


FIGURE 5-40 Holding the pipe in place by welding a piece of flat stock to the pipe and then clamping the flat stock to a pipe stand.

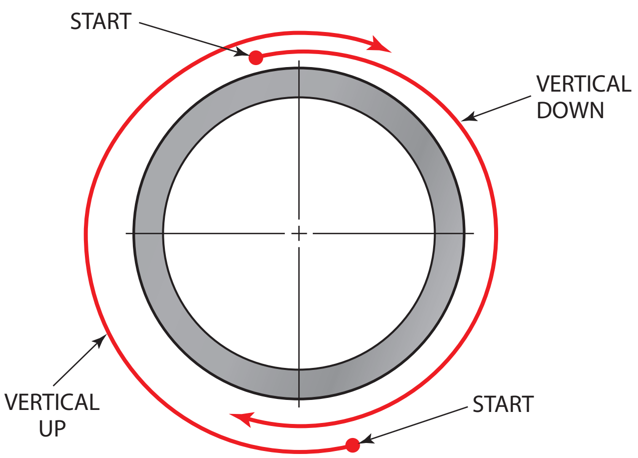


FIGURE 5-42 Stop at the 7 o'clock position.

position. Change the electrode angle to control the molten weld pool.

Repeat these stringer beads as needed, with each group of electrodes, until you can consistently make welds free of defects. Turn off the welding machine and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 5-8

Butt Joint, 5G Position, Using E6010 or E6011 Electrodes for the Root Pass and E7018 Electrodes for the Filler and Cover Passes

Using the same setup, materials, and procedures as listed in Practice 5-2, you will make a horizontal fixed 5G pipe weld. The root pass is to have 100% penetration over 80% or more of the length of the weld.

Mark the top of the pipe and mount it horizontally between waist and chest level. Weld the root pass uphill or downhill using E6010 or E6011 electrodes. Either grind the root pass or use a hot pass to clean out trapped slag.

Use E7018 electrodes for the filler and cover passes with stringer or weave patterns. When the weld is completed, visually inspect it for 100% penetration around 80% of the root length. Check the weld for uniformity and visual defects on the cover pass. Repeat the weld until you can consistently make welds free of defects. Turn off the welding machine and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

AWS SENSE CERTIFICATION TEST 5G

Once you have mastered the 5G pipe groove weld you may want to take the AWS SENSE pipe welding certification test outlined in Chapter 6.

PRACTICE 5-9

Butt Joint, 5G Position, Using E6010 or E6011 Electrodes

Using a properly set up and adjusted arc welding machine, proper safety protection, E6010 or E6011 arc welding electrodes with a 1/8 in. (3 mm) diameter, and two or more pieces of schedule 40 mild steel pipe 3 in. (76 mm) or larger in diameter, you will make a butt joint on a horizontally fixed 5G pipe.

Mark the top of the pipe and mount it between waist and chest level. Depending on the root gap, make a root weld uphill or downhill using E6010 or E6011 electrodes. Check the root penetration to determine if it is better in one area than in another area. Chip and wire brush the weld and set the machine for a hot pass. Start the hot pass at the bottom and weld upward on both sides. The bead should be kept uniform with little buildup.

Using stringer or weave beads, make the filler and cover welds. If stringer beads are used, downhill welds can be made. Cool, chip, and inspect the weld for uniformity and defects. Repeat this weld until you can consistently make welds free of defects. Turn off the welding machine and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

6G 45° INCLINED POSITION

The 45° **fixed inclined position** is thought to be the most difficult pipe position. Qualifying in this position will certify the welder in the other positions using the same size electrodes and pipe sizes. The weld must be uniform and not have defects even though its position is changing in more than one direction at a time, **Figure 5-43**.

During this weld, it is necessary to continuously change the weld pattern, electrode angle, and weld speed. Small multipass stringer beads work best. With experience, however, weave beads are possible.

PRACTICE 5-10

Stringer Bead, 6G Position, Using E6010 or E6011 Electrodes and E7018 Electrodes

Using the same setup, materials, and electrodes as listed in Practice 5-1, you will make straight stringer beads on a pipe in the 45° fixed inclined position.

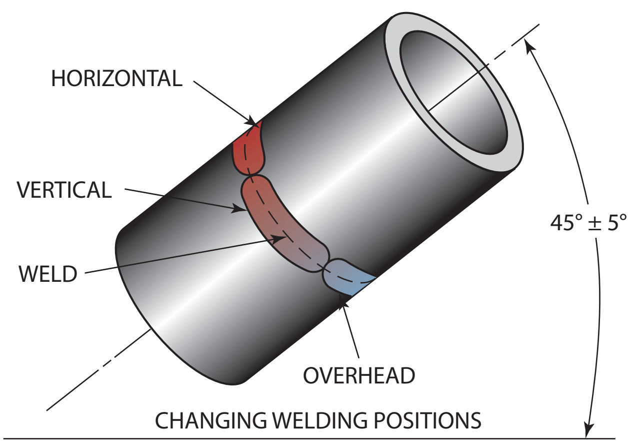


FIGURE 5-43 In the 6G position, the pipe is fixed at a 45° angle to the work surface. The effective welding angle changes as the weld progresses around the pipe.

Using the straight stepped "T" or whipping patterns, start at the bottom of the pipe with a keyhole technique. Keep the molten weld pool small and narrow for easier control. As the bead moves up to the side, the electrode angle should stay to the downhill side with a trailing (pulling) angle. When the weld passes beyond the side, the downhill and trailing angles are decreased. This is done so that when the weld reaches the top, the electrode is perpendicular to the top of the pipe. Repeat this procedure on the opposite side.

Repeat these stringer beads as needed, with both groups of electrodes, until you can consistently make welds free of defects. Turn off the welding machine and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

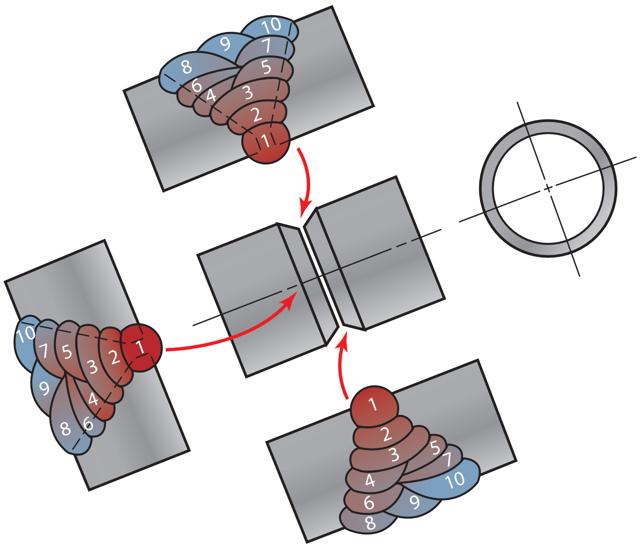


FIGURE 5-44 Weld bead positions for 6G pipe weld.

PRACTICE 5-11

Butt Joint, 6G Position, Using E6010 or E6011 Electrodes

Using a properly set up and adjusted arc welding machine, proper safety protection, E6010 or E6011 arc welding electrodes with a 1/8 in. (3 mm) diameter, and two or more pieces of schedule 40 mild steel pipe 3 in. (76 mm) or larger in diameter, you will make a butt joint on a pipe in the 45° fixed inclined position.

Starting at the top, make a vertical down root pass that ends just beyond the bottom. Repeat this weld on the other side. Chip and wire brush the slag so that an uphill hot pass can be made. The hot pass must be kept small and concave so that more slag will not be trapped along the downhill side. Clean the bead, turn down the machine amperage, and complete the joint with stringer beads, **Figure 5-44**.

Cool, chip, and inspect the completed weld for uniformity and defects. Repeat this weld until you can consistently make welds free of defects. Turn off the welding machine and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 5-12

Butt Joint, 6G Position, Using E6010 or E6011 Electrodes for the Root Pass and E7018 Electrodes for the Filler and Cover Passes

Using the same setup, materials, and procedures as listed in Practice 5-11, you will make a 45° fixed inclined pipe weld. The root pass is to have 100% penetration over 80% of the root length of the weld.

Make the root pass as a vertical up or down weld, depending on the root opening. Chip the slag and clean the weld by grinding or by using a hot pass. If a hot pass is used, chip and wire brush the joint. Using the E7018 electrode, start slightly before the center on the bottom and make a small stringer bead in an upward direction. Keep a trailing and a somewhat uphill electrode angle so that the weld is deposited on the bottom of the lower pipe. The next pass should use a downhill electrode angle so that the bead is on the uphill pipe. Alternate this process until the bead is complete. Clean the weld and inspect it for 100% penetration over 80% of the root length. Check for uniformity and visual defects on the cover pass. Repeat the weld until you can consistently make welds free of defects. Turn off the welding machine and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

AWS SENSE CERTIFICATION TEST 6G

Once you have mastered the 6G pipe groove weld you may want to take the AWS SENSE pipe welding certification test outlined in Chapter 6.

THINK GREEN

Do Not Overweld

Avoid overwelding a joint because excessive weld buildup on a pipe joint both wastes welding rods and power and takes more time to grind down to size.

Summary

Pipe welding is looked upon by many in the welding industry as the pinnacle of the welding trade. Pipe welding presents its own challenges to the welder because of the constantly changing weld position. With practice you learn to control the molten weld pool as it transitions through the various weld positions. As you learn to recognize the subtle changes in the weld pool, you will be able to make the welding technique changes as second nature.

As you observe a pipe welder in the field, you will notice that the welder spends a significant amount of time on the preparation of the equipment and pipe before any welding begins. Being properly set up and having the weld joint properly aligned before welding are essential in producing quality welded pipe joints.

Often there is a tendency to overweld pipe joints. You must also learn to control weld size. This is very important with pipe welds because too large of a weld can put more stresses on the joint. Also, a good pipe welded joint may have many small weld passes.

Review

1. List some applications that use low-pressure piping.
2. List some applications that use medium-pressure piping.
3. List some applications that use high-pressure piping.
4. Describe the differences between pipe and tubing.
5. What are the advantages of welded piping systems over other joining methods?
6. Why must the ends of pipe be beveled before being welded?
7. How can the ends of a pipe be beveled?
8. Why is the end of a pipe beveled at a 37 1/2° angle?
9. What causes root suck-back or a concave root face?
10. Why are arc strikes outside the welding zone considered a problem on pipe?
11. What are the purposes of backing rings?
12. What is the purpose of a hot pass?
13. Why must the weld crater be cleaned before starting a new electrode?
14. What is the maximum width of the cover pass? Why?
15. When is the 1G welding position used?
16. What can make welding in the 2G vertical fixed pipe position difficult?
17. What supports the welds on a 2G pipe joint?
18. On 5G welds, what usually determines the direction of the root pass?
19. What angle is the pipe at in the 6G position?
20. In addition to continuously changing the weld pattern, what other changes must be continually made when welding in the 6G position?

Chapter 6

Shielded Metal Arc Welding AWS SENSE Certification

OBJECTIVES

After completing this chapter, the student should be able to

- demonstrate the ability to make root passes with or without backing strips.
- demonstrate the ability to make a hot pass on plate and pipe.
- demonstrate how to make filler passes on plate and pipe.
- demonstrate how to make a cover pass on plate and pipe.
- demonstrate how to prepare bend test specimens for plate and pipe.
- demonstrate the ability to pass AWS SENSE Qualification Workmanship Samples.

KEY TERMS

back gouging
burnthrough
cover pass
filler passes
guided-bend
hot pass
interpass temperature
key hole
molten weld pool
multiple pass weld
postheating
preheating
root pass
wagon tracks
weld groove
weld specimen

INTRODUCTION

The SMAW process can be used to consistently produce high-quality welds. The practices in this chapter are designed to further develop the SMA welding skills that you learned in Chapters 4 and 5. The welds, if passed, that would qualify you for a SENSE certification are identified as either "AWS SENSE Level I" or "AWS SENSE Level II" workmanship samples. The weld practices that are not part of the SENSE certification are designed to help you develop the skills needed to successfully pass the SENSE welds. The practices are designed to give you the experience of taking code-type tests in a variety of materials and positions even if you choose not to participate in the SENSE program because welders are frequently required to make these types of welds to a code or standard. This chapter covers the high-quality welding of plate, pipe, and plate to pipe.

All workmanship parts must be mechanically cut or machine OF cut. The welding groove and plate surface within 1 in. (25 mm) must be mechanically cleaned (ground) to a bright finish.

ROOT PASS

The **root pass** is the first weld bead of a **multiple pass weld**. The root pass fuses the two parts together and establishes the depth of weld metal penetration. A good root pass is needed to obtain a sound weld. The root may be either open or closed, using a backing strip or backing ring, **Figure 6-1**.

The backing strip used in a closed root may remain as part of the weld, or it may be removed. Because leaving the backing strip on a weld may cause it to fail due to concentrations of stresses along the backing strip, removable backup tapes have been developed. Backup tapes are made of high-temperature ceramics, **Figure 6-2**, that can be used to control penetration and prevent burnthrough. The tape can be peeled off after the weld is completed. Most welds do not use backing strips.

On plates that have the joints prepared on both sides, the root face may be ground or gouged clean before another pass is applied to both sides, **Figure 6-3**. This practice has been applied to some large diameter pipes. However, welds that can be reached from only one side must be produced adequately, without the benefit of being able to clean and repair the back side.

The open root weld is widely used in plate and pipe designs. The face side of an open root weld is not as important as the root surface on the back or inside, **Figure 6-4**. The face of a root weld may have some areas of poor uniformity in width, reinforcement, and buildup or have other defects such as undercut or overlap. As long as the root surface is correct, the front side can be ground, gouged, or burned out to produce a sound weld, **Figure 6-5**. For this reason, during the root pass practices, the weld will be evaluated from the root side only as long as there are not too many defects on the face. To practice the open root welds, the welder will be using mild steel plate that is 1/8 in. (3 mm) thick. The root face for most grooved joints will be approximately the same size. This thin plate will help the welder build skill without taking too much time beveling plate just to practice the root pass. Two different methods are used to make a root pass. One method is used only on joints with little or no root gap. This method requires a high amperage and short arc length. The arc length is so short that the electrode flux may drag along on the edges of the joint. The setup for this method must be correct for it to work.

The other method can be used on joints with wide, narrow, or varying root gaps. A stepping electrode manipulation and key hole control the penetration. The electrode is moved in and out of the molten weld pool as the weld

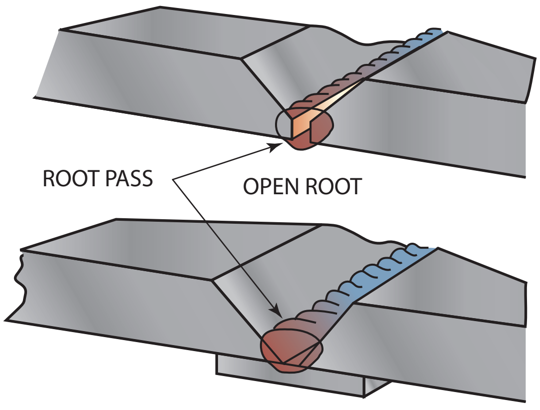
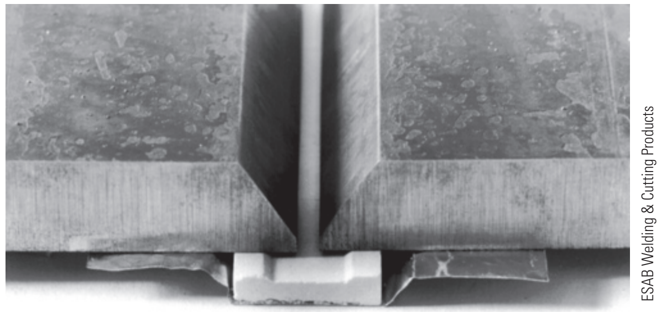


FIGURE 6-1 Root pass maximum deposit 1/4-in. (6-mm) thick.

(A) FIBERGLASS



(B) WELD ROOT PASS MADE USING CERAMIC BACKING TAPE

FIGURE 6-2 Welding backing tapes are available in different materials and shapes. (A) Ceramic backing with tape. (B) Ceramic backing with tape applied to a V groove.

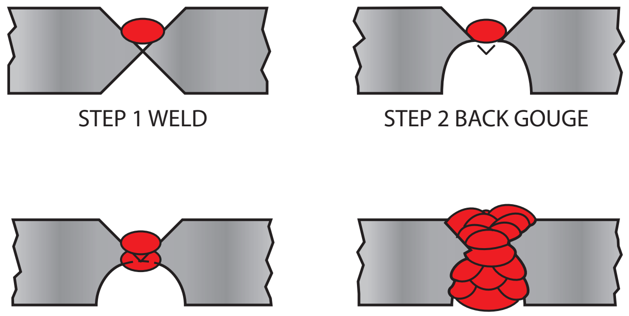


FIGURE 6-3 Using back gouging to ensure a sound weld root.

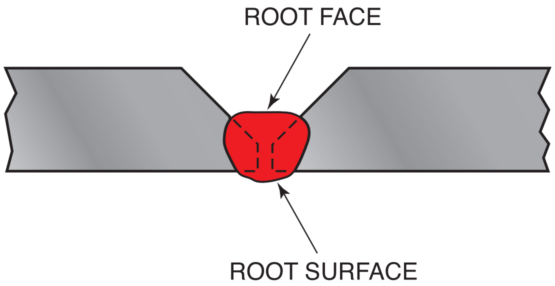


FIGURE 6-4 Ideal bead shape for the root pass.

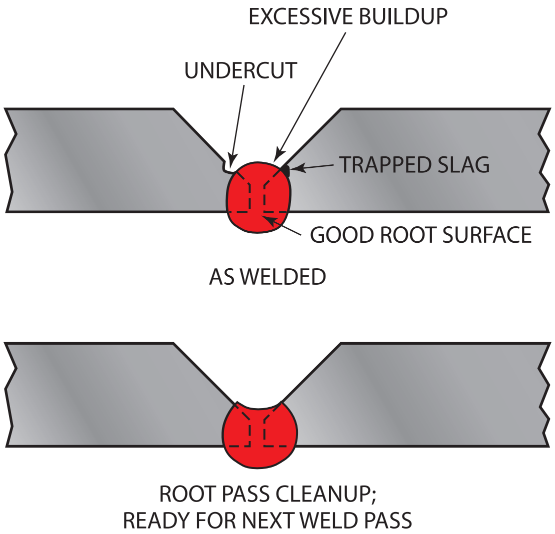


FIGURE 6-5 Grinding back the root pass to ensure a sound second pass.

progresses along the joint. The edge of the metal is burned back slightly by the electrode just ahead of the molten weld pool, **Figure 6-6**. This is referred to as a **key hole**, and metal flows through the key hole to the root surface.

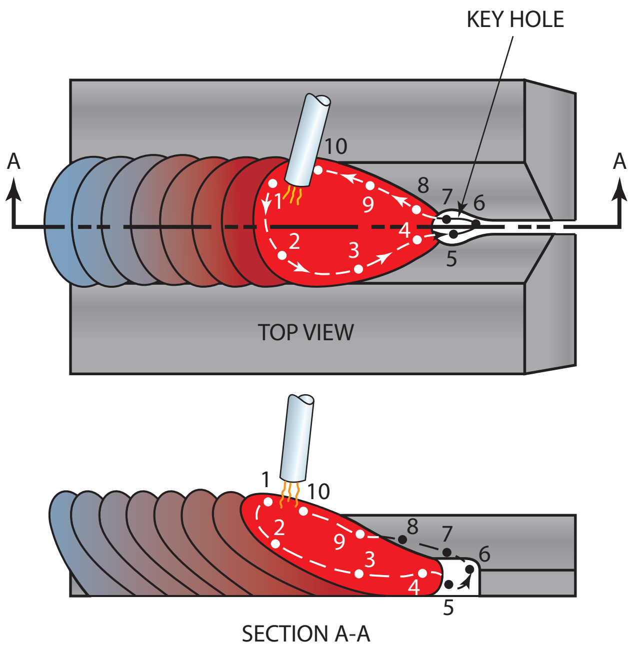


FIGURE 6-6 Electrode movement to open and use a key.

The key hole must be maintained to ensure 100% penetration. This method requires more welder skill and can be used on a wide variety of joint conditions. The face of the bead resulting from this technique often is defect-free.

THINK GREEN

Reduce Postweld Cleanup

The root face of a weld is as important as the weld face when it comes to weld strength and weld integrity. The ability to produce a root pass that has a smooth uniform contour and is free from defects reduces the time and expense of grinding and refinishing the root surface to meet the weld standard. Making a weld with an acceptable root surface saves both time and resources.

PRACTICE 6-1

Root Pass on Plate with a Backing Strip in All Positions

Using a properly set up and adjusted welding machine, proper safety protection, E6010 or E6011 arc welding electrodes with a 1/8 in. (3 mm) diameter, one or more pieces of mild steel plate 1/8 in. (3 mm) thick × 6 in. (152 mm) long, and one strip of mild steel 1/8 in. (3 mm) thick × 1 in. (25 mm) wide × 6 in. (152 mm) long, you will make a root weld in all positions, **Figure 6-7**. Tack weld the plates together with a 1/16-in. (2-mm) to 1/8-in. (3-mm) root opening. Be sure there are no gaps between the backing strip and plates when the pieces are tacked together, **Figure 6-8**. If there is a small gap between the backing strip and the plates, it can be removed by placing the assembled test plates on an anvil and striking the tack weld with a hammer. This will close the gap by compressing the tack welds, **Figure 6-9**.

Use a straight step or "T" pattern for this root weld. Push the electrode into the root opening so that there is good fusion with the backing strip and bottom edge of the plates. Failure to push the penetration deep into the joint will result in a cold lap at the root, **Figure 6-10**.

Watch the **molten weld pool** and keep its size as uniform as possible. As the molten weld pool increases in size, move the electrode out of the weld pool. When the weld pool begins to cool, bring the electrode back into the molten weld pool. Use these weld pool indications to determine how far to move the electrode and when to return to the molten weld pool. After completing the weld, cut the plate and inspect the cross-section of the weld for good fusion at the edges. Repeat the welds as necessary until you can consistently make welds free of defects. Turn off the welding machine and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

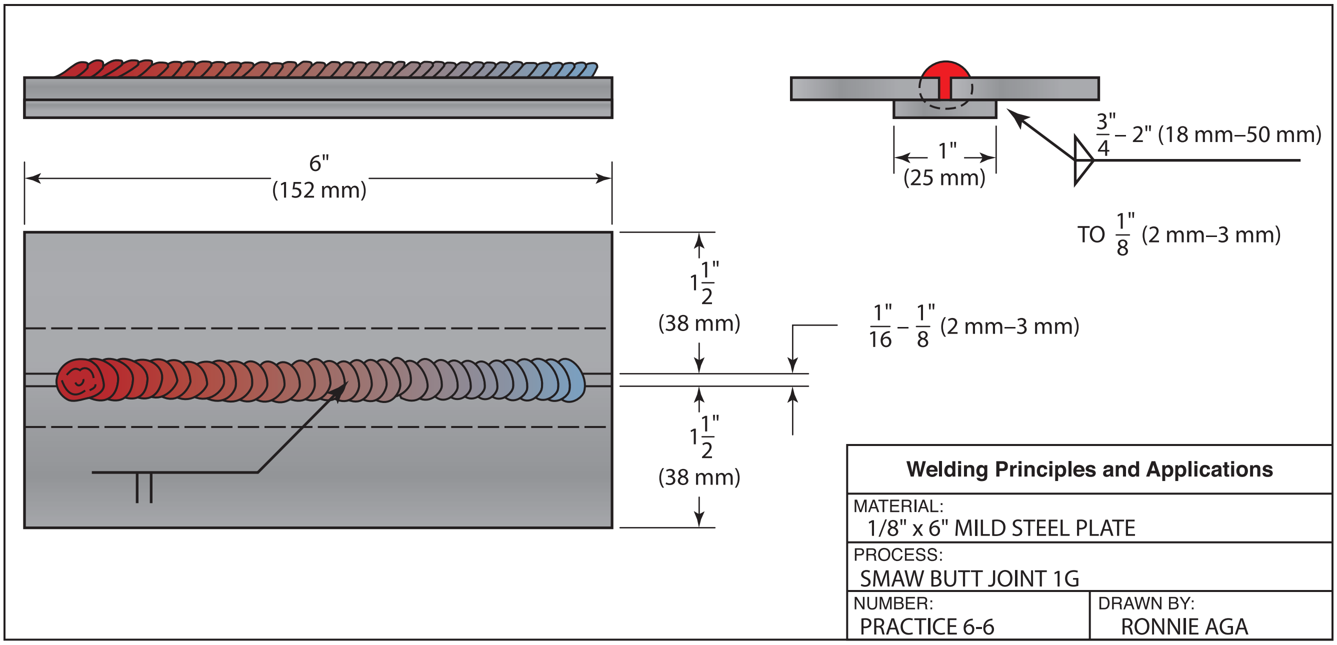


FIGURE 6-7 Square butt joint with a backing strip.

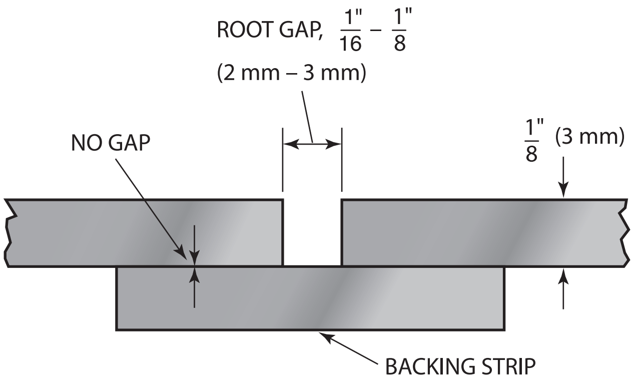


FIGURE 6-8 Backing strip.

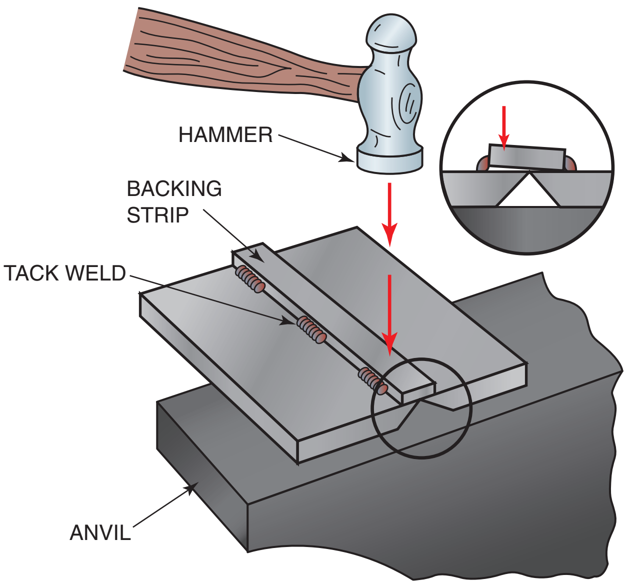


FIGURE 6-9 Using a hammer to align the backing strip and weld plates.

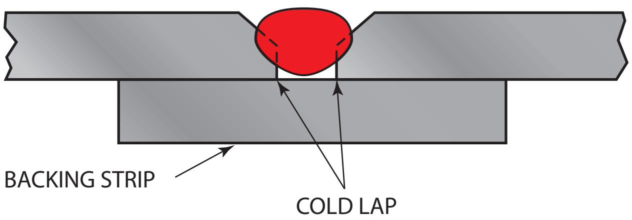


FIGURE 6-10 Incomplete root fusion.

PRACTICE 6-2

Root Pass on Plate with an Open Root in All Positions

Using a properly set up and adjusted arc welding machine, proper safety protection, E6010 or E6011 arc welding electrodes with a 1/8 in. (3 mm) diameter, and two or more pieces of mild steel plate 6 in. (152 mm) long × 1/8 in. (3 mm) thick, you will make a welded butt joint in all positions with 100% root penetration.

- Tack weld the plates together with a root opening of 0 in. (0 mm) to 1/16 in. (2 mm).
- Using a short arc length and high amperage setting, make a weld along the joint.

You can change the electrode angle to control penetration and burnthrough. As the trailing angle is decreased, making the electrode flatter to the plate, penetration, depth, and burnthrough decrease, **Figure 6-11**, because both the arc force and heat are directed away from the bottom of the joint back toward the weld. Surface tension holds the metal in place, and the mass of the bead quickly cools the molten weld pool holding it in place. Increasing the electrode angle toward the perpendicular will increase penetration depth and possibly cause more burnthrough. The arc force

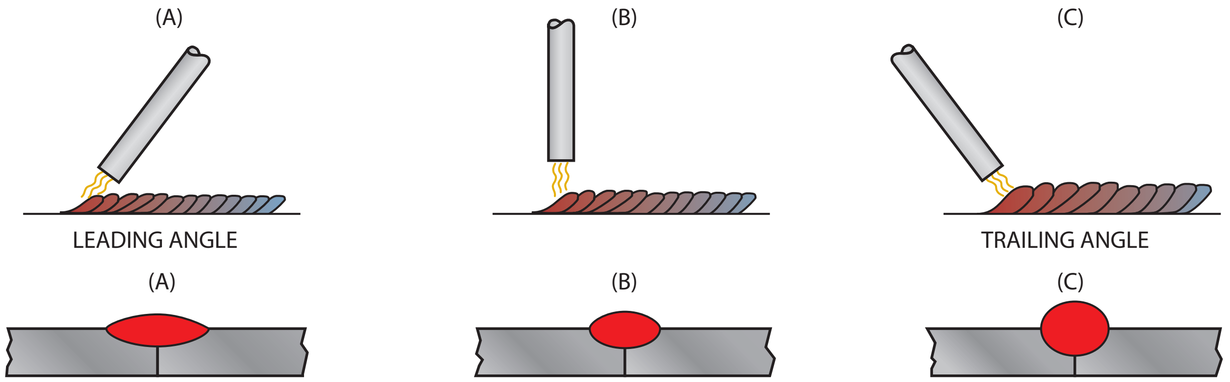


FIGURE 6-11 Effect of rod angle on weld bead shape. (A) Leading angle. (B) Perpendicular. (C) Trailing.

and heat focused on the gap between the plates will push the molten metal through the joint.

The electrode holder can be slowly rocked from side to side while keeping the end of the electrode in the same spot on the joint, **Figure 6-12**. This will allow the arc force to better tie in the sides of the root to the base metal.

- When a burnthrough occurs, rapidly move the electrode back to a point on the weld surface just before the burnthrough.
- Lower the electrode angle and continue welding. If the burnthrough does not close, then stop the weld, chip, and wire brush the weld.
- Check the size of the burnthrough. If it is larger than the diameter of the electrode, then the root pass must be continued with the step method described in Practice 6-3. If the burnthrough is not too large, lower the amperage slightly and continue welding.
- Watch the color of the slag behind the weld. If the weld metal is not fusing to one side, the slag will be brighter in color on one side. The brighter color is caused by the slower cooling of the slag because there is less fused metal to conduct the heat away quickly.
- After the weld is completed, cooled, and chipped, check the back side of the plate for good root penetration. The root should have a small bead that will look as though it was welded from the back side, **Figure 6-13**. The penetration must be completely free of any drips of metal from the root face, called "icicles."

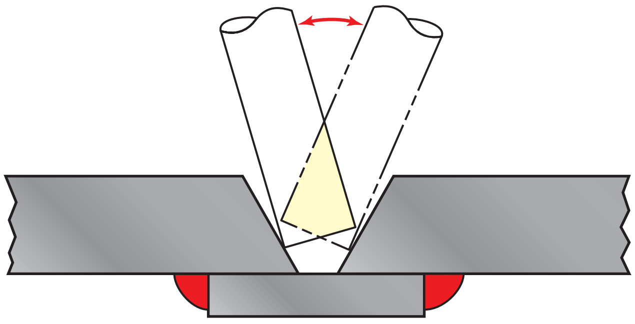


FIGURE 6-12 Rocking the top of the electrode while keeping the end in the same place helps control the bead shape.

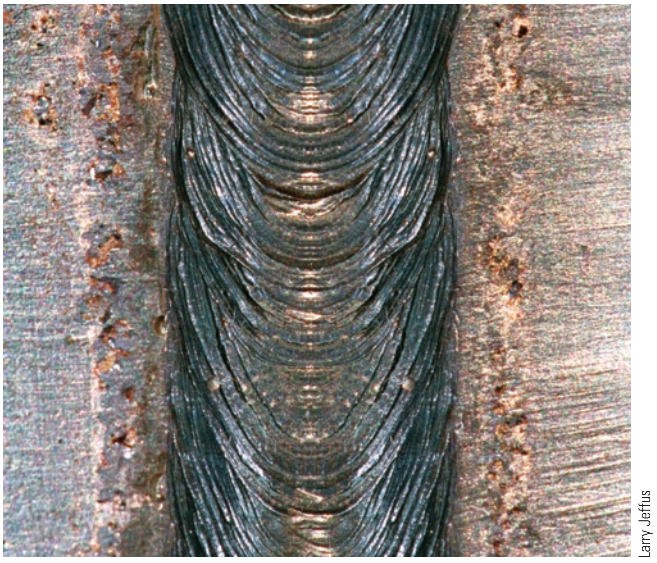


FIGURE 6-13 The root face (inside) appears uniform.

- Repeat the welds as necessary until you can consistently make welds free of defects. Turn off the welding machine and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 6-3

Open Root Weld on Plate Using the Step Technique in All Positions

Using the same setup, materials, and electrodes as described in Practice 6-2, you will make a welded butt joint in all positions with 100% root penetration.

Tack weld the plates together with a root opening from 0 in. (0 mm) to 1/8 in. (3 mm). Using a medium amperage setting and a short stepping electrode motion, make a weld along the joint.

The electrode should be pushed deeply into the root to establish a key hole that will be used to ensure 100% root penetration. Once the key hole is established, the electrode

is moved out and back in the molten weld pool at a steady, rhythmic rate. Watch the molten weld pool and key hole size to determine the rhythm and distance of electrode movement.

If the molten weld pool size decreases, the key hole will become smaller and may close completely. To increase the molten weld pool size and maintain the key hole, slow the rate of electrode movement and shorten the distance the electrode is moved away from the molten weld pool. This will increase the molten weld pool size and penetration because of increased localized heating.

If the molten weld pool becomes too large, metal may drip through the key hole, forming an icicle on the back side of the plate. Extremely large molten weld pool sizes can cause a large hole to be formed or cause **burnthrough**. Repairing large holes can require much time and skill. To keep the molten weld pool from becoming too large, increase the travel speed, decrease the angle, shorten the arc length, or lower the amperage, **Table 6-1**.

The distance the electrode is moved from the molten weld pool and the length of time in the molten weld pool are found by watching the molten weld pool. The molten weld pool size increases as you hold the arc in the molten weld pool until it reaches the desired size, approximately twice the electrode diameter, **Figure 6-14**. Move the electrode ahead of the molten weld pool, keeping the arc in the joint but being careful not to deposit any slag or metal ahead of the weld. To prevent metal and/or slag from transferring, raise the electrode to increase the arc length, **Figure 6-15**. Keep moving the electrode slowly forward as you watch the molten weld pool. The molten weld pool will suddenly start to solidify. At that time, move the electrode quickly back to the molten weld pool before it totally solidifies. Moving the electrode in a slight arc will raise the electrode ahead of the molten weld pool and automatically lower the electrode when it returns to the molten weld pool. Metal or slag deposited ahead of the molten weld pool may close the key hole, reduce penetration, and cause slag inclusions. Raising the end of the electrode too high or moving it too far ahead of the molten weld pool can cause all of the shielding gas to be blown away from the molten weld pool. If this happens, oxides can cause porosity. Keeping the electrode movement in balance takes concentration and practice.

	Amperage	Travel Speed	Electrode Size	Electrode Angle
To decrease puddle size	Decrease	Increase	Decrease	Leading
To increase puddle size	Increase	Decrease	Increase	Trailing

TABLE 6-1 Changes Affecting Molten Weld Bead Size

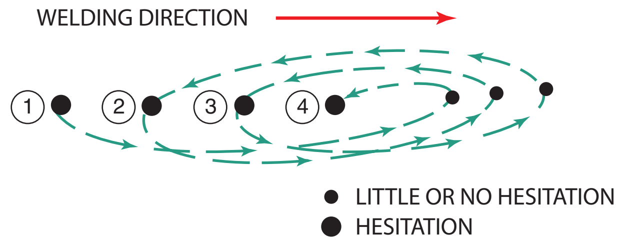


FIGURE 6-14 Weave pattern used to control the molten weld bead size.

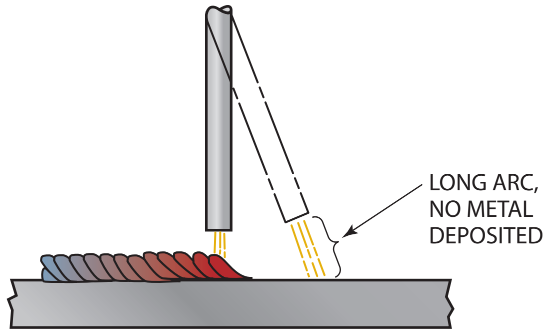


FIGURE 6-15 A long arc prevents metal or slag from being deposited ahead of the weld bead.

Changing from one welding position to another requires an adjustment in timing, amperage, and electrode angle. The flat, horizontal, and overhead positions use approximately the same rhythm, but the vertical position may require a shorter time cycle for electrode movement. The amperage for the vertical position can be lower than that for the flat or horizontal, but the overhead position uses nearly the same amperage as flat and horizontal. The electrode angle for the flat and horizontal positions is approximately the same. For the vertical position, the electrode uses a sharper leading angle than does overhead, which is nearly perpendicular and may even be somewhat trailing.

Cool, chip, wire brush, and inspect both sides of the weld. The root surface should be slightly built up and look as though it was welded from that side (refer to Figure 6-13). Repeat the welds as necessary until you can consistently make welds free of defects. Turn off the welding machine and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

HOT PASS

The surface of a root pass may be irregular and/or have undercut, overlap, slag inclusions, or other defects, depending on the type of weld, the code or standards, and the condition of the root pass. The surface of a root pass can be cleaned by grinding or by using a hot pass.

On critical, high-strength code welds, it is usually required that the root pass as well as each filler pass be ground (refer to Figure 6-5). This grinding eliminates weld discontinuities caused by slag entrapments. It also can be used to remove most of the E60 series weld metal so that the stronger weld metal can make up most of the weld. When high-strength, low-alloy welding electrodes are used, this grinding is important to remove most of the low-strength weld deposit. This will leave the weld made up of nearly 100% of the high-strength weld metal, **Figure 6-16**.

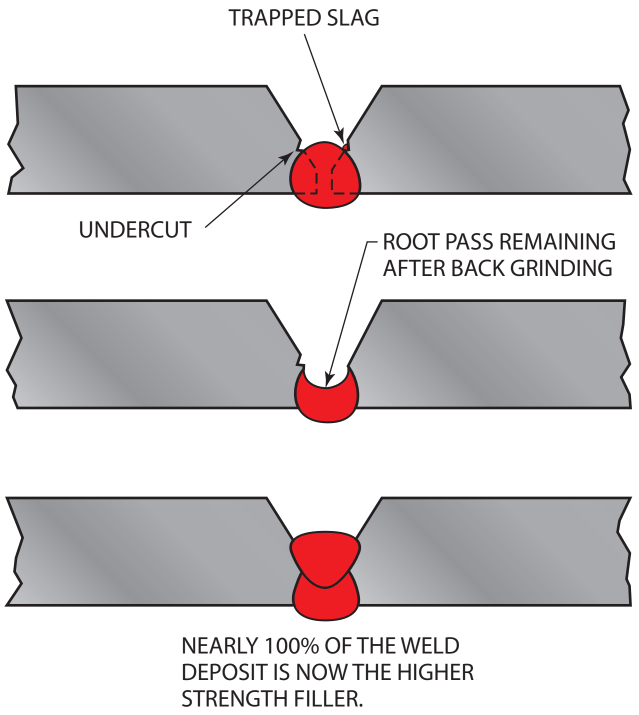


FIGURE 6-16 Back grinding to remove both undercut and trapped slag discontinuities; filler metal is used for the hot pass.

The fastest way to clean out trapped slag and make the root pass more uniform is to use a **hot pass**. The hot pass uses a higher-than-normal amperage setting and a fast travel rate to reshape the bead and burn out the trapped slag. After chipping and wire brushing the root pass to remove all the slag possible, a welder is ready to make the hot pass. The ideal way to apply a hot pass is to rapidly melt a large surface area, **Figure 6-17**, so that the trapped slag can float to the surface. The slag, mostly silicon dioxide (SiO_2), may not melt itself so the surrounding steel must be melted to enable it to float free. The silicon dioxide may not melt because it melts at approximately 3100°F (1705°C), which is more than 500°F (270°C) hotter than the temperature at which the surrounding steel melts, approximately 2600°F (1440°C).

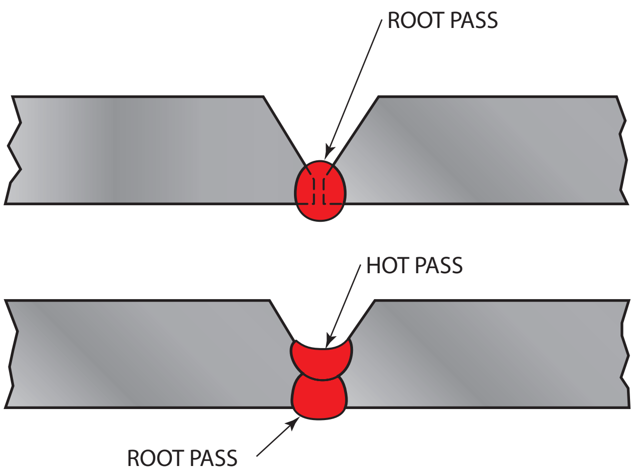


FIGURE 6-17 Using the hot pass to clean the face of the root pass.

A very small amount of metal should be deposited during the hot pass so that the resulting weld is concave. A concave weld, compared to a convex weld, is more easily cleaned by chipping, wire brushing, or grinding. Failure to clean the convex root weld will result in a discontinuity showing up on an X-ray. Such discontinuities are called **wagon tracks**, **Figure 6-18**.

The hot pass can also be used to repair or fill small spots of incomplete fusion or pinholes left in the root pass.

The normal weave pattern for a hot pass is the straight step or "T" pattern. The "T" can be used to wash out stubborn trapped slag better than the straight step pattern. The frequency of electrode movement is dependent on the time required for the molten weld pool to start cooling. As with the root pass, metal or slag should not be deposited ahead of the bead. Do not allow the molten weld pool to cool completely or let the shielding gas covering be blown away from the molten weld pool.

The hot pass technique can also be used to clean some welds that may first require grinding or gouging for a repair. The penetration of the molten weld pool must be deep enough to free all trapped slag and burn out all porosity.

EXPERIMENT 6-1

Hot Pass to Repair a Poor Weld Bead

Using a properly set up and adjusted arc welding machine, proper safety protection, E6010 or E6011 arc welding electrodes with a 1/8 in. (3 mm) diameter, and two or more plates that have welds containing slag inclusions, lack of fusion, porosity, or other defects, you will make a hot pass to burn out the defects.

Chip and wire brush the weld bead. If necessary, use a punch to break apart large trapped slag deposits. The poorer the condition of the weld, the more vertical the joint should be for the hot pass. Large slag deposits tend to float around the molten weld pool and stay trapped in deep pockets in the flat position. With the weld in the vertical position, the slag can run out of the joint and down the face of the weld. Set the amperage as high as possible without overheating and burning up the electrode. Start at the bottom and weld upward using a combination of straight step and "T" patterns to keep the weld deposit uniform. Watch the back edge of the molten weld pool for size and the weld crater for the complete burning out of impurities, **Figure 6-19**.

The plate may start to become overheated because of the high heat input. If you notice that the weld bead is starting to cool too slowly and is growing in length, then you should stop welding, **Figure 6-20**. Allow the plate to cool before continuing the weld.

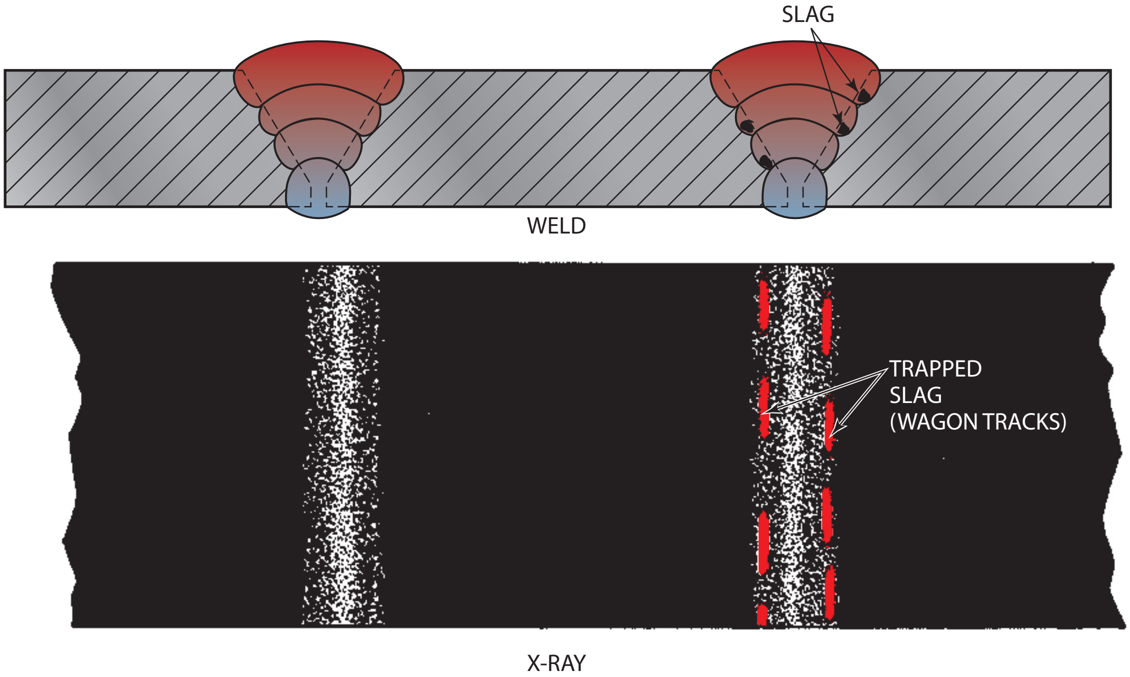


FIGURE 6-18 Slag trapped between passes will show on an X-ray.

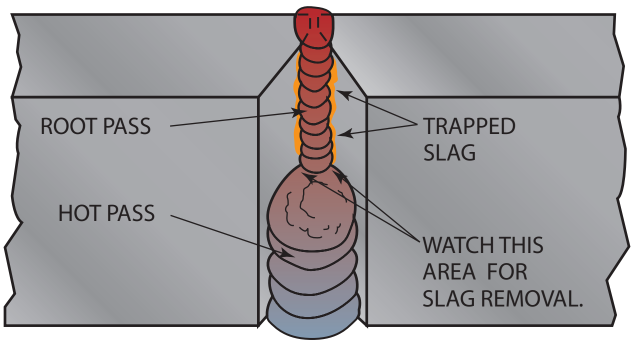


FIGURE 6-19 Burning out trapped slag by using a hot pass.

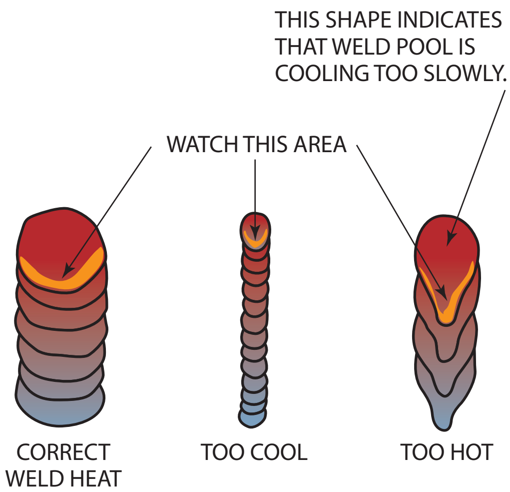


FIGURE 6-20 Watch the back edge of the weld pool to determine the correct current.

CAUTION

This hot pass technique is designed to be used on noncritical, noncode welds only. It should not be used to cover bad welds, or as a means of repairing the work of a welder who is less skilled.

After the weld is completed, cool, chip, and inspect it for uniformity. The plate can be cut at places where you know large discontinuities existed before to see if they were repaired or only covered up. If you wish, this experiment can be repeated on other defects and joints.

Welds that have large defects in addition to excessive buildup may require some grinding to remove the buildup. Turn off the welding machine and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

FILLER PASS

After the root pass is completed and it has been cleaned, the groove is filled with weld metal. These weld beads make up the **filler passes**. More than one pass is often required.

Filler passes are made with stringer beads or weave beads. For multiple pass welds, the weld beads must overlap along the edges. They should overlap enough so that the finished bead is smooth, **Figure 6-21**. Stringer beads usually overlap approximately 50%, and weave beads overlap approximately 25%.

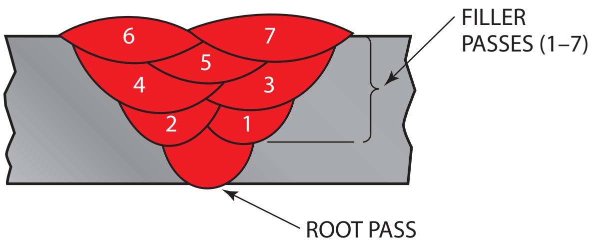


FIGURE 6-21 Filler passes: maximum thickness 1/8 in. (3 mm) for each pass.

Each weld bead must be cleaned before the next bead is started. Slag left on the plate between welds cannot be completely burned out because filler welds should be made with a low amperage setting. Deep penetration will slow the rate of buildup in the joint. Deeply remelting the previous weld metal may weaken the joint. All that is required of a filler weld is that it be completely fused to the base metal.

Chipping, wire brushing, and grinding are the best ways to remove slag between filler weld passes. After the weld is completed, it can be checked by ultrasonic or radiographic nondestructive testing. Most schools are not equipped to do this testing. Therefore, a quick check for soundness can be made by destructive testing. One method of testing the deposited weld metal is by cutting and cross-sectioning the weld with an abrasive wheel and inspecting the weld. Another fast way to inspect filler passes is to cut a groove through the weld with a gouging tip. Watch the hot metal as it is washed away. The black spots that appear in the cut are slag inclusions. If only a few small spots appear, then the weld probably will pass most tests. But if a long string or large pieces of inclusions appear, then the weld will most likely fail.

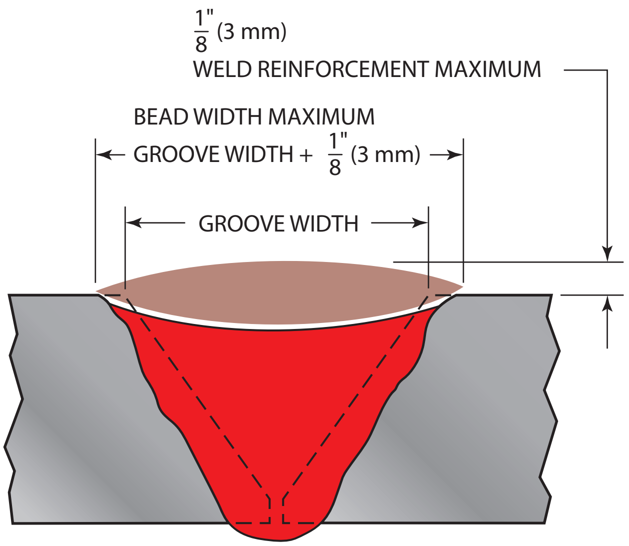


FIGURE 6-22 The cover pass should not be excessively large.

Larry Jeffus

FIGURE 6-23 Practice cover pass.

COVER PASS

The last weld bead on a multipass weld is known as the **cover pass**. The cover pass may use a different electrode weave, or it may be the same as the filler beads. Keeping the cover pass uniform and neat-looking is important. Most welds are not tested, and often the inspection program is only visual. Thus, the appearance might be the only factor used for accepting or rejecting welds.

The cover pass should be free of any visual defects such as undercut, overlap, porosity, or slag inclusions. It should be uniform in width and reinforcement. A cover pass should not be more than 1/8 in. (3 mm) wider than the groove opening, **Figure 6-22**. Cover passes that are too wide do not add to the weld strength.

The cover pass may be made as one wide weld or as a series of two or more stringer beads, **Figure 6-23**. If stringer beads are used, each bead should overlap the edge of the previous bead by one-quarter to one-half of its width. Both ends of the weld may taper down.

If it is important that the ends be square, tabs can be welded on the end of the joint to provide a place to start and stop the welds. The tabs are removed once the weld is completed. The backing strip on a test plate can be used the same way so that there is no under-fill at the beginning or ending of the welds, **Figure 6-24**.

PLATE PREPARATION

When welding on thick plate, it is impossible or impractical for the welder to try to get 100% penetration without preparing the plate for welding. The preparation of the plate is usually in the form of a **weld groove**. The groove can be cut into one side or both sides of the plate, and it may be cut into either just one plate or both plates of the joint, **Figure 6-25**. The type, depth, angle, and location of the groove are usually determined by a code standard that has been qualified for the specific job.

FIGURE 6-24 Run-off tabs help control possible under-fill or burn back at the starting and stopping points of a groove weld.

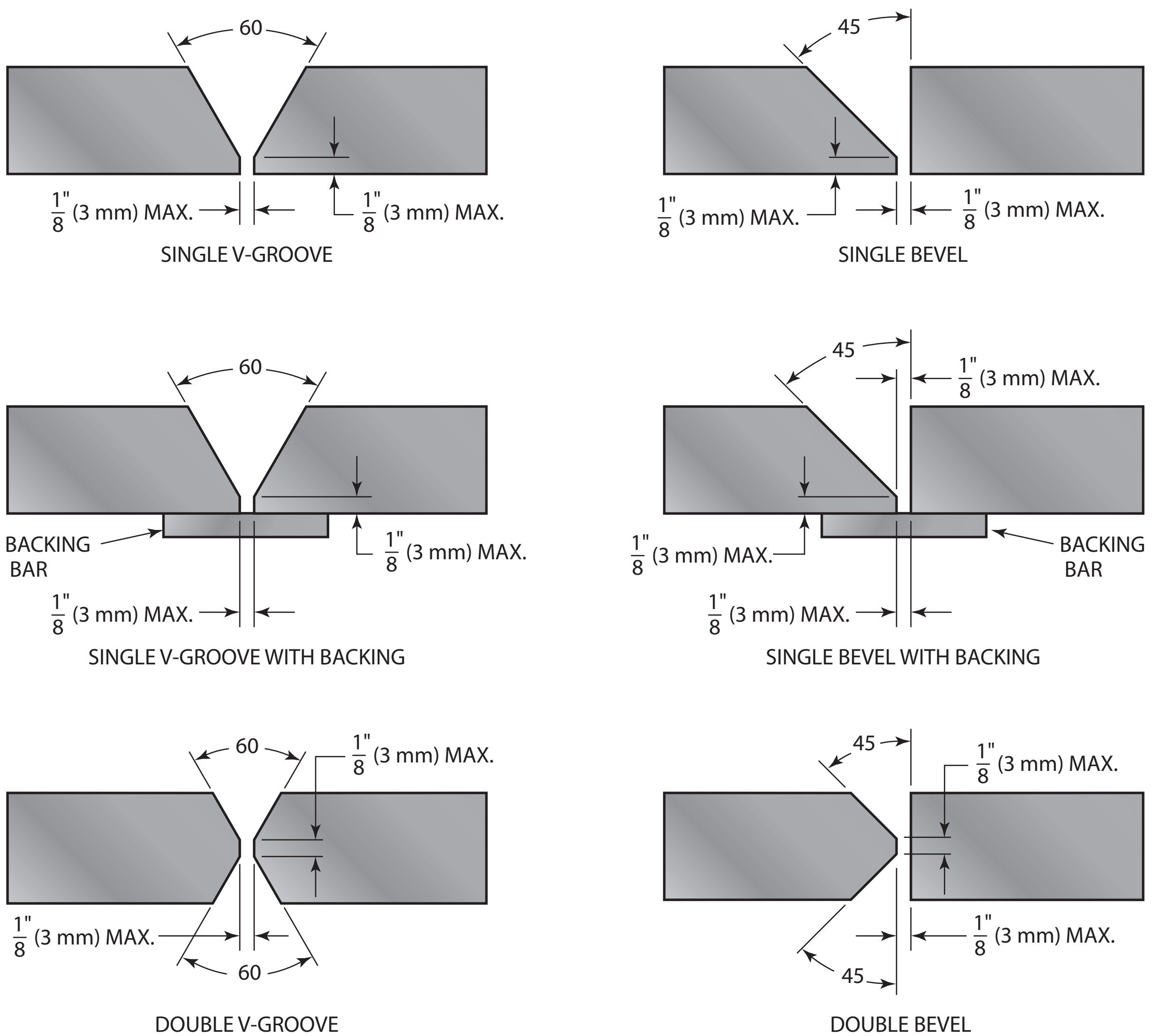


FIGURE 6-25 Typical butt joint preparations.

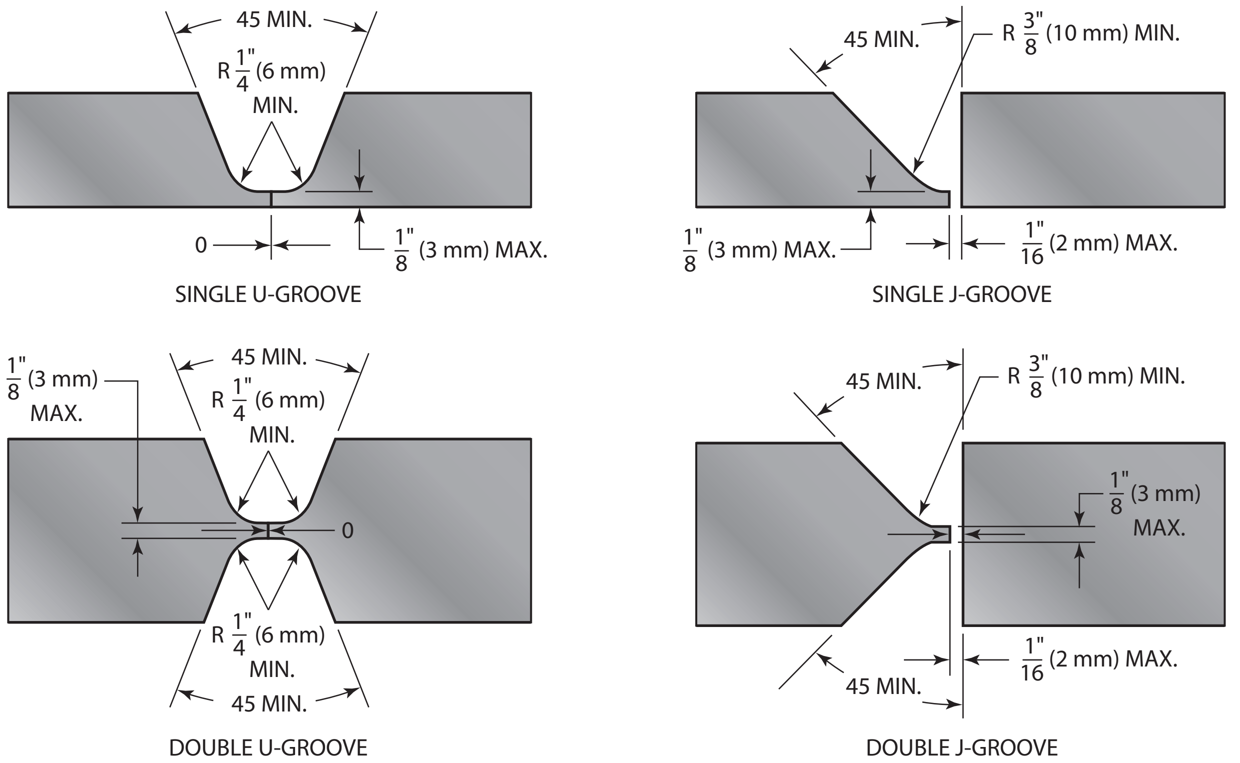


FIGURE 6-26 Typical butt joint preparations.

For SMA welds on plate 1/4 in. (6 mm) or thicker that need to have a weld with 100% joint penetration, the plate must be grooved. The groove may be ground, flame cut, plasma cut, gouged, or machined on the edge of the plate before or after the assembly. Bevels and V-grooves are best if they are cut before the parts are assembled. J-grooves and U-grooves can be cut either before or after assembly, **Figure 6-26**. The lap joint is seldom prepared with a groove because little or no strength can be gained by grooving this joint. The only advantage to grooving the lap joint design is to give additional clearance.

Plates that are thicker than 3/8 in. (10 mm) can be grooved on both sides but may be prepared on only one side. The choice to groove one or both sides is usually determined by joint design, position, and application. A tee joint in thick plate is easier to weld and will have less distortion if it is grooved on both sides. Plate in the flat position is usually grooved on only one side unless it can be repositioned. Welds that must have little distortion or that are going to be loaded equally from both sides are usually grooved on both sides. Sometimes plates are either grooved and welded or just welded on one side, and then back gouged and welded, **Figure 6-27**. **Back gouging** is a process of cutting a groove in the back side of a joint that has been welded. Back gouging can ensure 100% fusion at the root and remove discontinuities of the root pass. This process can also remove the root pass metal if the properties of the metal are not desirable to the finished weld, **Figure 6-28**. After back gouging, the groove is then welded. See Section 3 for more information on the various methods of gouging.

Heavy plate and pipe sections requiring preparations are often used in products manufactured under a code or standard. The American Welding Society (AWS), American Society of Mechanical Engineers (ASME), and American Bureau of Ships are a few of the agencies that issue codes and specifications. The AWS D1.1 and the ASME Boiler and Pressure Vessel (BPV) Section IX standards are used in this chapter as the standards for multiple pass groove welds that will be tested. The groove depth and angle are determined by the plate or pipe thickness and process. Chapter 22 covers these and other codes for welding plate and pipe.

Refer to Section 3 for information on beveling. After the plate is beveled, a grinder can be used to clean off oxides and improve the fit-up.

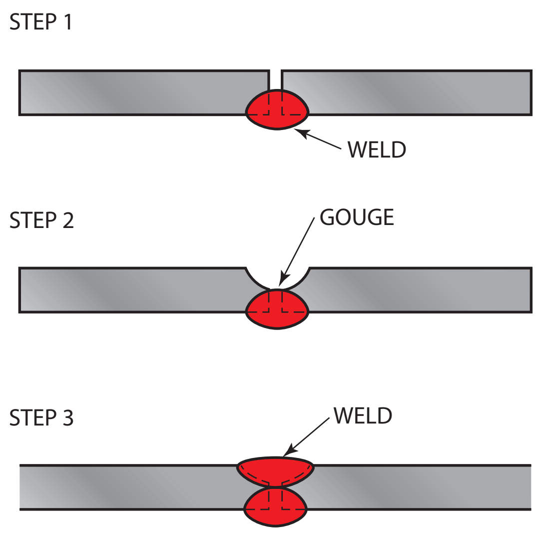


FIGURE 6-27 Back gouging sequence for a weld to ensure 100% joint penetration.

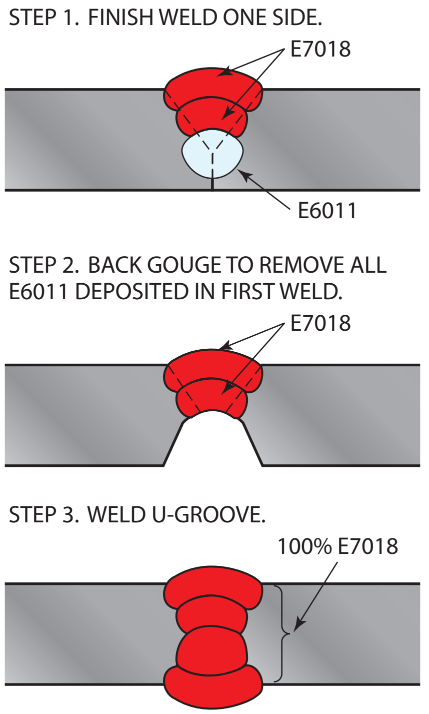


FIGURE 6-28 Back gouging to remove all weld metal used for the root pass or tacking.

RESTARTING A WELD BEAD

On all but short welds, the welding bead will need to be restarted after a welder stops to change electrodes. Because the metal cools as a welder changes electrodes and chips slag when restarting, the penetration and buildup may be adversely affected.

When a weld bead is nearing completion, it should be tapered so that when it is restarted the buildup will be more uniform. To taper a weld bead, the travel rate should be increased just before welding stops. A 1/4-in. (6-mm) taper is all that is required. The taper allows the new weld to be started and the depth of penetration reestablished without having excessive buildup, **Figure 6-29**.

The slag should always be chipped and the weld crater should be cleaned each time before restarting the weld. This is important to prevent slag inclusions at the start of the weld.

The arc should be restarted in the joint ahead of the weld. The electrodes must be allowed to heat up so that the arc is stabilized and a shielding gas cloud is reestablished to protect the weld. Hold a long arc as the electrode heats up so that metal is not deposited. Slowly bring the electrode downward and toward the weld bead until the arc is directly on the deepest part of the crater where the crater meets the plate in the joint, **Figure 6-30**. The electrode should be low enough to start transferring metal. Next, move the electrode in a semicircle near the back edge of the weld crater. Watch the buildup and match your speed in the semicircle to the deposit rate so that the weld is built up evenly, **Figure 6-31**. Move the electrode ahead and continue with the same weave pattern that was being used previously.

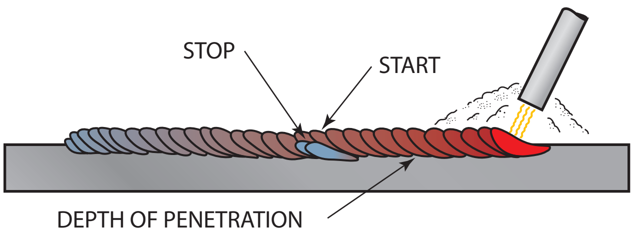


FIGURE 6-29 Tapering the size of the weld bead helps keep the depth of penetration uniform.

The movement to the root of the weld and back up on the bead serves both to build up the weld and reheat the metal so that the depth of penetration will remain the same. If the weld bead is started too quickly, penetration is reduced and buildup is high and narrow.

Starting and stopping weld beads in corners should be avoided. Tapering and restarting are especially difficult in corners, and this often results in defects, **Figure 6-32.**

PREHEATING AND POSTHEATING

Preheating Preheating is the application of heat to the metal before it is welded. This process helps to reduce cracking, hardness, distortion, and stresses by reducing the thermal shock from the weld and slowing the cool-down rate. **Preheating** is most often required on large, thick plates, when the plate is very cold, on days when the temperature is very cold, when small diameter electrodes are used, on high-carbon or manganese steels, on complex shapes, or with fast welding speeds.

Postheating Postheating is the application of heat to the metal after welding. **Postheating** is used to slow the cooling rate and reduce hardening.

Interpass temperature Interpass temperature is the temperature of the metal during welding. The **interpass temperature** is given as a minimum and maximum. The minimum temperature is usually the same as the preheat temperature. If the plate cools below this temperature during welding, it should be reheated. The maximum temperature may be specified to keep the plate below a certain phase change temperature for the mild steel used in these practices. The maximum interpass temperature occurs when the weld bead cannot be controlled because of a slow cooling rate. When this happens, the plate should be allowed to cool down, but not below the minimum interpass temperature.

If, during the welding process, a welder must allow a practice weldment to cool so that the weld can be completed later, the weldment should be cooled slowly and then reheated before starting to weld again. A weld that is to be tested or that is done on any parts other than scrap should not be quenched in water.

With the practices that are to be tested in this chapter, preheating should be used if the base metal to be welded is

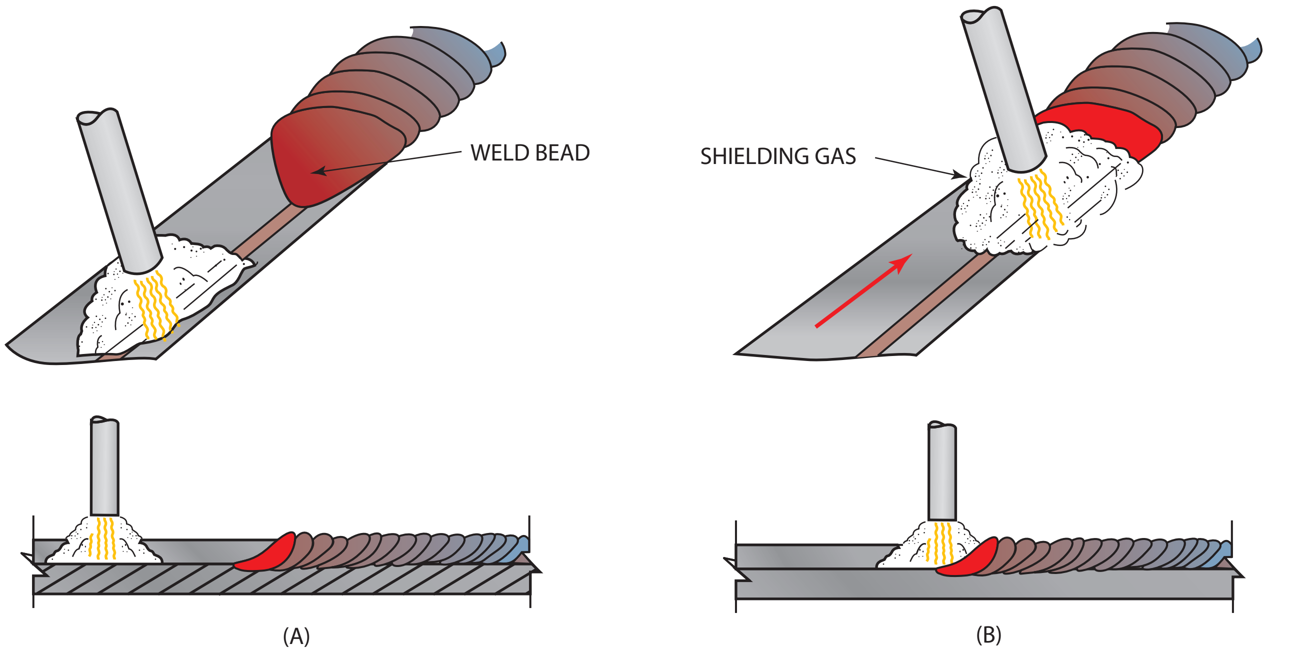


FIGURE 6-30 When restarting the arc, strike the arc ahead of the weld in the joint (A). Hold a long arc and allow time for the electrode to heat up, forming the protective gas envelope. Move the electrode so that the arc is focused directly on the leading edge (root) of the previous weld crater (B).

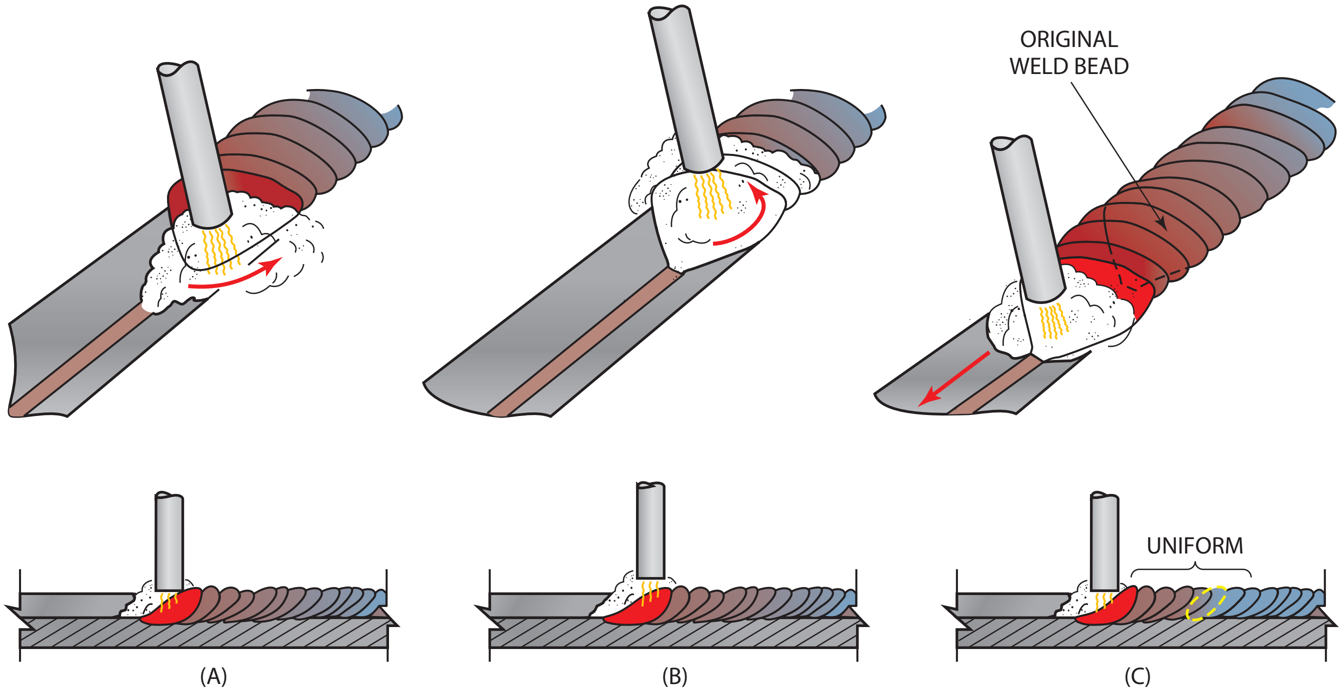


FIGURE 6-31 When restarting the weld pool after the root has been heated to the melting temperature, move the electrode upward along one side of the crater (A). Move the electrode along the top edge depositing new weld metal (B). When the weld is built up uniformly with the previous weld, continue along the joint (C).

very cold. It may also be used to reduce distortion on thick sections and to reduce hardness caused by the rapid cooling of the weld, which may occur in weld failure. Preheating the metal will slow the weld cooling rate, which results in a more ductile weld. **Table 6-2** lists the recommended preheat temperatures for plain carbon steels.

AWS WORKMANSHIP STANDARD FOR PREPARATION OF BASE METAL

All workmanship parts must be mechanically cut or machine OF cut. The specification on the cleanliness of the metal and for the groove face tolerances are based on the

FIGURE 6-32 Correct method of welding through a corner. Stopping on a corner may cause leaks.

Plate Thickness in. (mm)	Minimum Temperature	
	°F	°C
Up to 1/2 in. (13 mm)	70	21
1/2 in. (13 mm) to 1 in. (25 mm)	100	38
1 in. (25 mm) to 2 in. (51 mm)	200	95
Over 2 in. (51 mm)	300	150

TABLE 6-2 Preheat Temperatures for Arc Welding on Low Carbon Steel

AWS D1.1. All hydrocarbons and other contaminants, such as cutting fluids, grease, oil, and primers, must be cleaned off all parts and filler metals before welding. This cleaning can be done with any suitable solvents or detergents.

The backing strip, groove face, and inside and outside plate surfaces within 1 in. (25 mm) of the joint must be mechanically cleaned of slag, rust, and mill scale. Cleaning must be done with a wire brush or grinder down to bright metal.

Any roughness or notches that are deeper than 1/64 in. (0.4 mm) are unacceptable and must be ground smooth.

AWS VISUAL INSPECTION CRITERIA

All welds must pass a visual inspection before they are qualified to be bend tested. The Visual Inspection Criteria are from AWS QC-10 and AWS QC-11 and they are the same for both Level I and Level II welds.

- There shall be no cracks and no incomplete fusion. There shall be no incomplete joint penetration in groove welds except as permitted for partial joint penetration welds.
- The test supervisor shall examine the weld for acceptable appearance and shall be satisfied that the welder is skilled in using the process and procedure specified for the test.
- Undercut shall not exceed the lesser of 10% of the base metal thickness or 1/32 in. (0.8 mm).
- Where visual examination is the only criterion for acceptance, all weld passes are subject to visual examination at the discretion of the test supervisor.
- The frequency of porosity shall not exceed one in each 4 in. (100 mm) of weld length, and the maximum diameter shall not exceed 3/32 in. (2.4 mm).
- Welds shall be free from overlap.

PREPARING SPECIMENS FOR BEND TESTING

The detailed preparation of specimens for testing in this chapter is based on the structural welding codes AWS D1.1, AWS B4.0, AWS QC10, and AWS QC11, and the ASME BPV Code, Section IX. The maximum allowable size of fissures (cracks or openings) in a **guided-bend** test specimen is given in codes for specific applications. Copies of these publications are available from the appropriate organizations. More information on tests and testing can be found in Chapter 25.

WS SPECIMEN PREPARATION CRITERIA

Preparation

Correct **weld specimen** preparation is essential for reliable results. The weld must be uniform in width and reinforcement and have no undercut or overlap. The weld reinforcement and backing strip, if used, must be removed flush to the surface, **Figure 6-33**. They can be machined or ground off. The plate thickness after removal must be a minimum of 3/8 in. (10 mm); for pipe, the thickness must be equal to the pipe's original wall thickness. Locate the specimens to be cut out according to **Figure 6-34**. The specimens may be cut out of the test weldment using an abrasive disk, by sawing, or by cutting with a torch. Flame-cut specimens must be cut slightly wider so that when the edges are ground or machined smooth, the specimen will not be too narrow, **Figure 6-35**. The grinding on the sides of thermally cut specimens is done to remove the heat-affected zone caused by the cut.

All corners must be rounded to a radius of 1/8 in. (3 mm) maximum, and all grinding or machining marks must run lengthwise on the specimen, **Figure 6-36**. Rounding the corners and keeping all marks running lengthwise reduce the chance that a good weld specimen will fail due to poor surface preparation.

Testing

One is to be prepared for a transverse face bend, and the other is to be prepared for a transverse root bend, **Figure 6-37**.

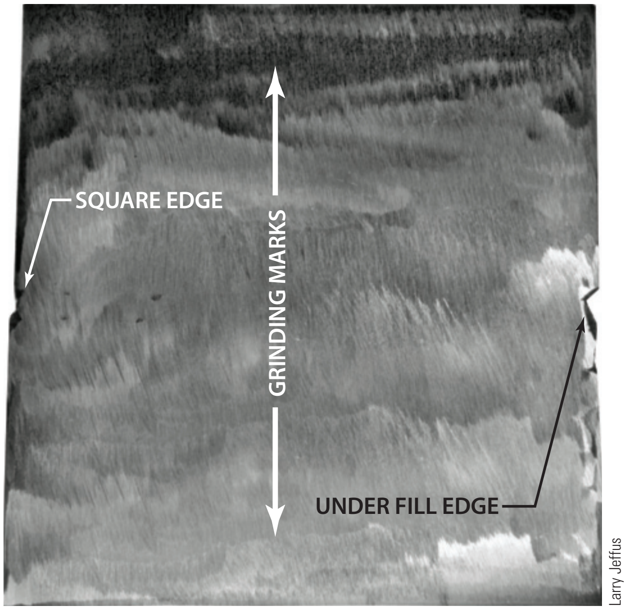


FIGURE 6-33 Plate ground in preparation for removing test specimens.

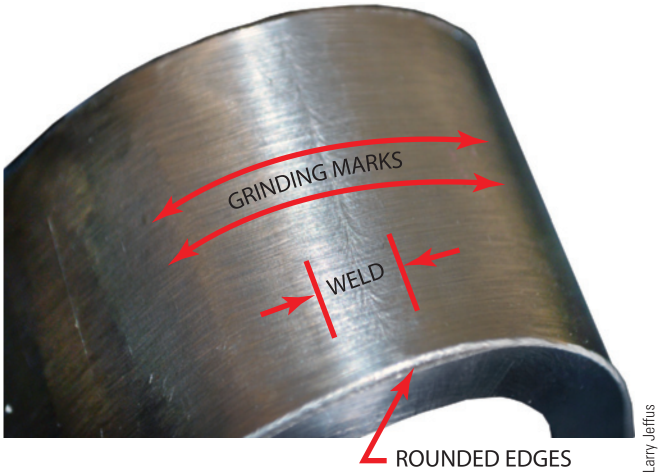


FIGURE 6-36 Guided bend test specimen.

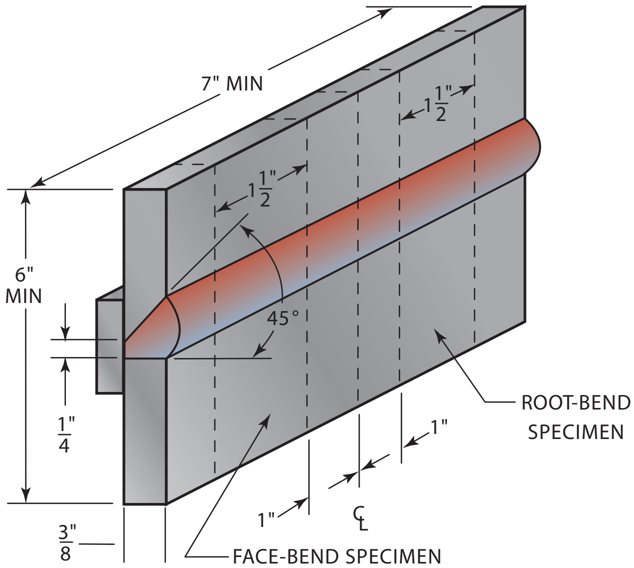


FIGURE 6-34 Sequence for removing guided bend specimens from the plate once welding is complete.

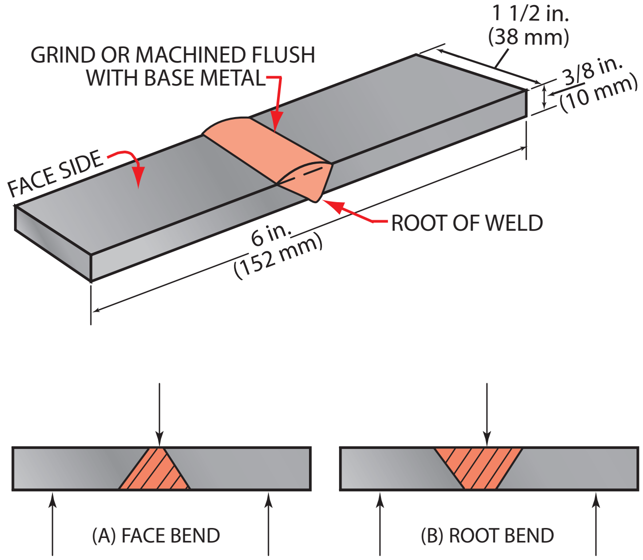


FIGURE 6-37 Face and root bends.

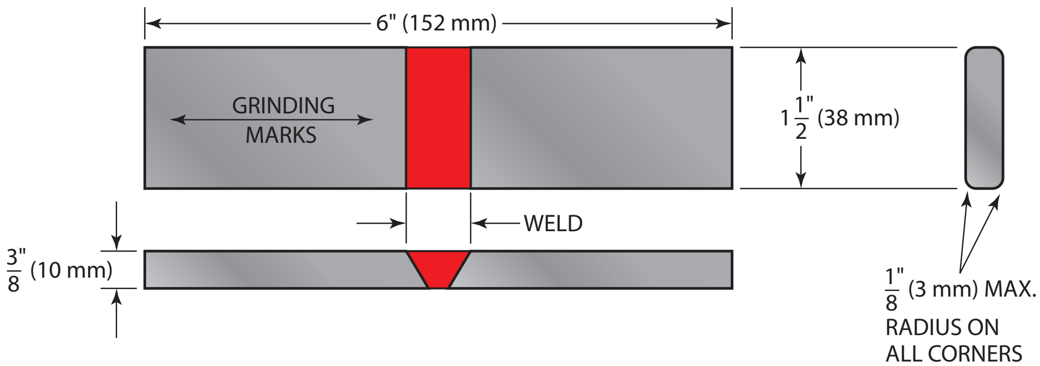


FIGURE 6-35 Guided bend specimen.

NOTE

Lightly oiling or greasing the sides of the test specimen can help to reduce the stretching forces across the weld caused by bend test jigs that do not have roller bearings on the shoulders of the bending jig.

- Transverse face bend. The weld is perpendicular to the longitudinal axis of the specimen and is bent so that the weld face becomes the tension surface of the specimen.
- Transverse root bend. The weld is perpendicular to the longitudinal axis of the specimen and is bent so that the weld root becomes the tension surface of the specimen.

AWS ACCEPTANCE CRITERIA FOR BEND TEST

For acceptance, the convex surface of the face-bend and root-bend specimens shall meet both of the following requirements:

1. No single indication shall exceed 1/8 in. (3.2 mm) measured in any direction on the surface.
2. The sum of the greatest dimensions of all indications on the surface that exceed 1/32 in. (0.8 mm) but are less than or equal to 1/8 in. (3.2 mm) shall not exceed 3/8 in. (9.5 mm).

Cracks occurring at the corner of the specimens shall not be considered unless there is definite evidence that they result from slag or inclusions or other internal discontinuities.

PRACTICE 6-4 AWS SENSE

Welding Procedure Specification (WPS)

Welding Procedures Specifications No.: PRACTICE 6-4.

Title:
Welding SMAW of plate to plate.

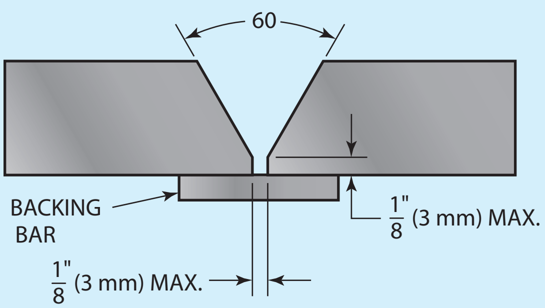
Scope:
This procedure is applicable for V-groove plate with a backing strip within the range of 1/8 in. (3 mm) through 1-1/2 in. (38 mm). Welding may be performed in the following positions: 1G, 2G (AWS SENSE Level I), 3G Vertical Up (AWS SENSE Level I), and 4G.

Base Metal:
The base metal shall conform to Plain Carbon Steel. Backing material specification Plain Carbon Steel.

Filler Metal:
The filler metal shall conform to AWS specification No. E7018 from AWS specification A5.1. This filler metal falls into F-number F4 and A-number A-1.

Shielding Gas:
The shielding gas, or gases, shall conform to the following compositions and purity: N/A.

Joint Design and Tolerances:



SINGLE V-GROOVE WITH BACKING

Preparation of Base Metal:
All workmanship parts must be prepared according to the AWS Workmanship Standard for Preparation of Base Metal.

Electrical Characteristics:
The current shall be AC or DCEP. The base metal shall be on the work lead or negative side of the line.

Preheat:
The parts must be heated to a temperature higher than 70°F (21°C) before any welding is started.

Backing Gas:
N/A.

Welding Technique:
Tack weld the plates together with the backing strip. There should be approximately a 1/8-in. (3-mm) root gap between the plates. Use the E7018 arc welding electrodes to make a root pass to fuse the plates and backing strip together. Clean the slag from the root pass and use either a hot pass or grinder to remove any trapped slag.

Using the E7018 arc welding electrodes, make a series of filler welds in the groove until the joint is filled. Figure 6-21 shows the recommended location sequence for the weld beads.

Interpass Temperature:
The plate should not be heated to a temperature higher than 350°F (175°C) during the welding process. After each weld pass is completed, allow it to cool; the weldment must not be quenched in water.

Cleaning:
The slag can be chipped and/or ground off between passes but can only be chipped off of the cover pass.

Visual Inspection Criteria for Entry-Level Welders:
The weld must pass a visual inspection by the instructor or test supervisor based on the AWS Visual Inspection Criteria.

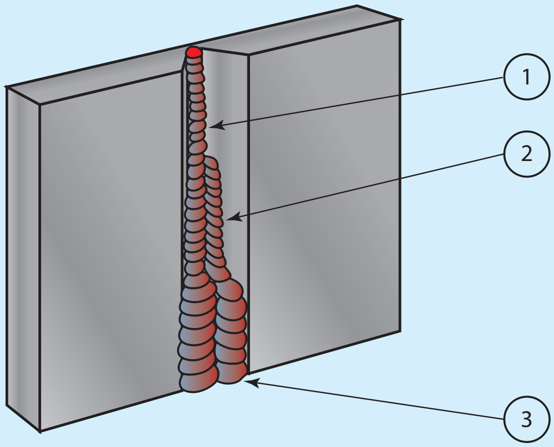
Complete a copy of the Workmanship Visual Inspection Report form listed in Appendix I or provided by your instructor.

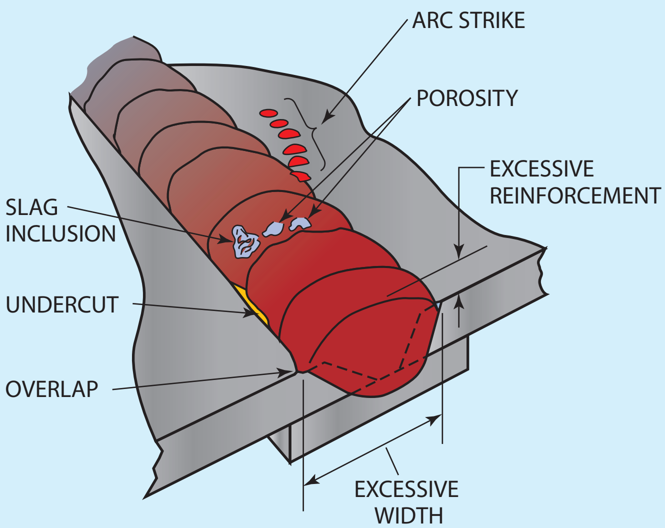
Bend Test:
The weld is to be mechanically tested only after it has passed the visual inspection. Be sure that the test specimens are properly marked to identify the welder, the position, and the process.

Specimen Preparation:
The weld must be prepared for bend testing in accordance to the AWS Specimen Preparation Criteria.

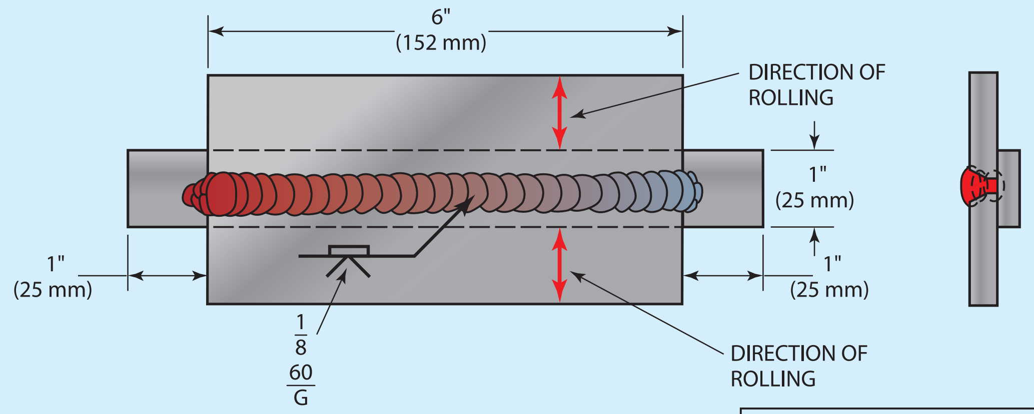
Acceptance Criteria for Bend Test:
The bent specimen must not exceed any of the acceptable limits of discontinuities as listed in the AWS Acceptance Criteria for Bend Test.

Repair:
No repairs of defects are allowed.





Sketches:



Welding Principles and Applications	
MATERIAL: 3/8" x 6" MILD STEEL PIPE	
PROCESS: SMAW BUTT JOINT 1G	
NUMBER: PRACTICE 6-4	DRAWN BY: RONNIE AGA

Paperwork:

Compete a "Bill of Materials," "Time Sheet," and "Performance Qualification Test Record" in Appendix I or as provided by your instructor.

Complete a copy of the Face-Bend and Root-Bend Test Results report form listed in Appendix I or provided by your instructor.

PRACTICE 6-5

Welding Procedure Specification (WPS)

Welding Procedures Specifications No.: PRACTICE 6-5.

Title:
Welding SMAW of plate to plate.

Scope:
This procedure is applicable for V-groove plate without a backing strip within the range of 3/8 in. (10 mm) through 3/4 in. (20 mm).

Welding may be performed in the following positions: 1G, 2G, 3G, and 4G.

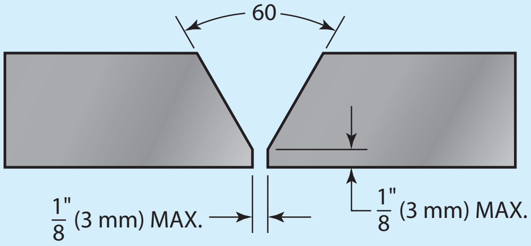
Base Metal:
The base metal shall conform to M1020 or A36.

Backing material specification: None.

Filler Metal:
The filler metal shall conform to AWS specification No. E6010 or E6011 root pass and E7018 for the cover pass from AWS specification A5.1. This filler metal falls into F-numbers F3 and F4 and A-number A-1.

Shielding Gas:
The shielding gas, or gases, shall conform to the following compositions and purity: N/A.

Joint Design and Tolerances:



Preparation of Base Metal:
All workmanship parts must be prepared according to the AWS Workmanship Standard for Preparation of Base Metal.

Electrical Characteristics:
The current shall be AC or DCEP. The base metal shall be on the work lead or negative side of the line.

Preheat:
The parts must be heated to a temperature higher than 70°F (21°C) before any welding is started.

Backing Gas:
N/A.

Welding Technique:
Tack weld the plates together; there should be an approximately 1/8-in. (3-mm) root gap between the plates. Use the E6010 or E6011 arc welding electrodes to make a root pass to fuse the plates together. Clean the slag from the root pass and use either a hot pass or grinder to remove any trapped slag.

Using the E7018 arc welding electrodes, make a series of filler welds in the groove until the joint is filled. The drawing on the next page shows the recommended location sequence for the weld beads.

Interpass Temperature:
The plate, outside of the heat-affected zone, should not be heated to a temperature higher than 350°F (175°C) during the welding process. After each weld pass is completed, allow it to cool; the weldment must not be quenched in water.

Cleaning:
The slag can be chipped and/or ground off between passes but can only be chipped off of the cover pass.

Visual Inspection Criteria for Entry-Level Welders:
The weld must pass a visual inspection by the instructor or test supervisor based on the AWS Visual Inspection Criteria.

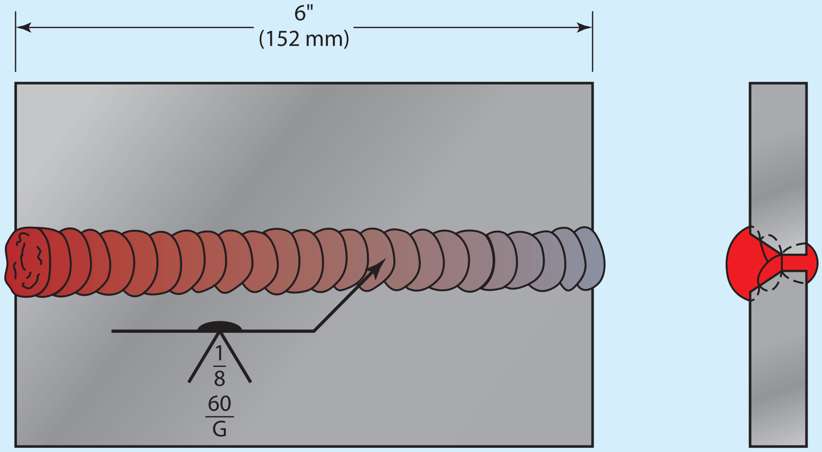
Bend Test:
The weld is to be mechanically tested only after it has passed the visual inspection. Be sure that the test specimens are properly marked to identify the welder, the position, and the process.

Specimen Preparation:
The weld must be prepared for bend testing in accordance to the AWS Specimen Preparation Criteria.

Acceptance Criteria for Bend Test:
The bent specimen must not exceed any of the acceptable limits of discontinuities as listed in the AWS Acceptance Criteria for Bend Test.

Repair:
No repairs of defects are allowed.

Sketches:



Welding Principles and Applications	
MATERIAL: 3/8" TO 3/4" x 6" MILD STEEL PLATE	
PROCESS: SMAW BUTT JOINT 1G, 2G, 3G & 4G	
NUMBER: PRACTICE 6-5	DRAWN BY: KRISTI WEBB

Paperwork:
Compete a "Bill of Materials," "Time Sheet," and "Performance Qualification Test Record" in Appendix I or as provided by your instructor.

Complete a copy of the Face-Bend and Root-Bend Test Results report form listed in Appendix I or provided by your instructor.

PRACTICE 6-6

Welding Procedure Specification (WPS)

Welding Procedures Specifications No.: PRACTICE 6-6.

Title:
Welding SMAW of pipe to pipe.

Scope:
This procedure is applicable for V-groove pipe within the range of 3 in. (76 mm) schedule 40 through 8 in. (203 mm) schedule 40.

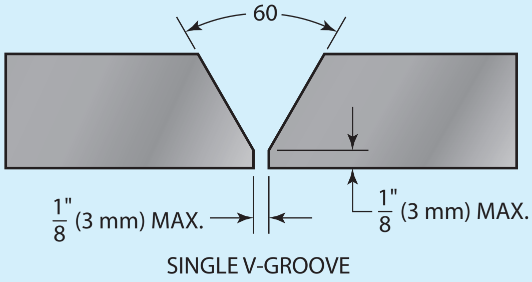
Welding may be performed in the following positions: 1G, 2G, 5G, and 6G.

Base Metal:
The base metal shall conform to Carbon Steel M-1/P/1S-1, Group 1 or 2. Backing material specification: N/A.

Filler Metal:
The filler metal shall conform to AWS specification No. E6010 or E6011 root pass and E7018 for the cover pass from AWS specification A5.1. This filler metal falls into F-numbers F3 and F4 and A-number A-1.

Shielding Gas:
The shielding gas, or gases, shall conform to the following compositions and purity: N/A.

Joint Design and Tolerances:



Preparation of Base Metal:
All workmanship parts must be prepared according to the AWS Workmanship Standard for Preparation of Base Metal.

Electrical Characteristics:
The current shall be AC or DCEP. The base metal shall be on the work lead or negative side of the line.

Preheat:
The parts must be heated to a temperature higher than 70°F (21°C) before any welding is started.

Backing Gas:
N/A.

Welding Technique:
Tack weld the pipes together; there should be an approximately 1/8-in. (3-mm) root gap between the pipe ends. Use the E6010 or E6011 arc welding electrodes to make a root pass to fuse the pipe ends together. Clean the slag from the root pass and use either a hot pass or grinder to remove any trapped slag.

Using the E7018 arc welding electrodes, make a series of filler welds in the groove until the joint is filled. **Figure 6-38** shows the recommended location sequence for the weld beads for the 1G and 5G positions, **Figure 6-39** shows the recommended location sequence for the 2G position, and **Figure 6-40** shows the recommended location sequence for the 6G position.

Interpass Temperature:
The plate should not be heated to a temperature higher than 350°F (175°C) during the welding process. After each weld pass is completed, allow it to cool; the weldment must not be quenched in water.

Cleaning:
The slag can be chipped and/or ground off between passes but can only be chipped off of the cover pass.

Visual Inspection Criteria for Entry-Level Welders:
The weld must pass a visual inspection by the instructor or test supervisor based on the AWS Visual Inspection Criteria.

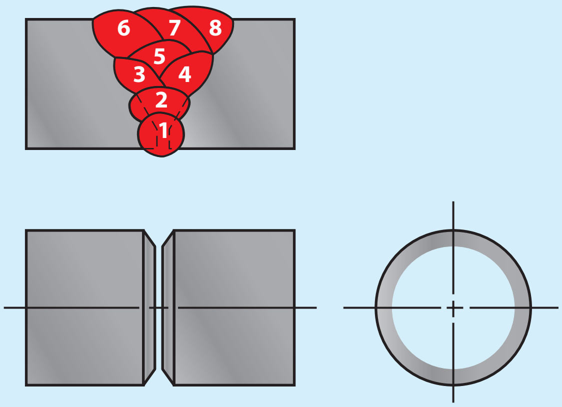


FIGURE 6-38 Weld bead sequence for 1G and 5G positions.

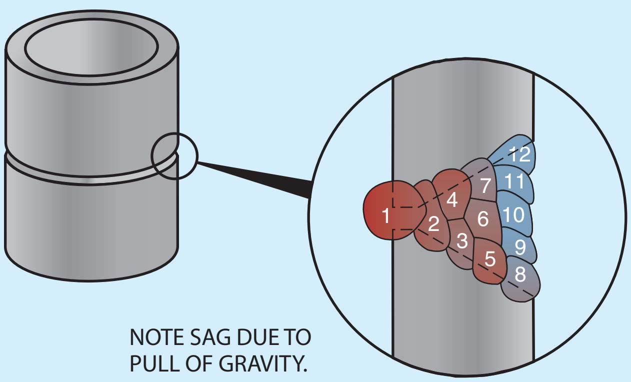


FIGURE 6-39 Correct sequence for applying welds to a pipe in the 2G position.

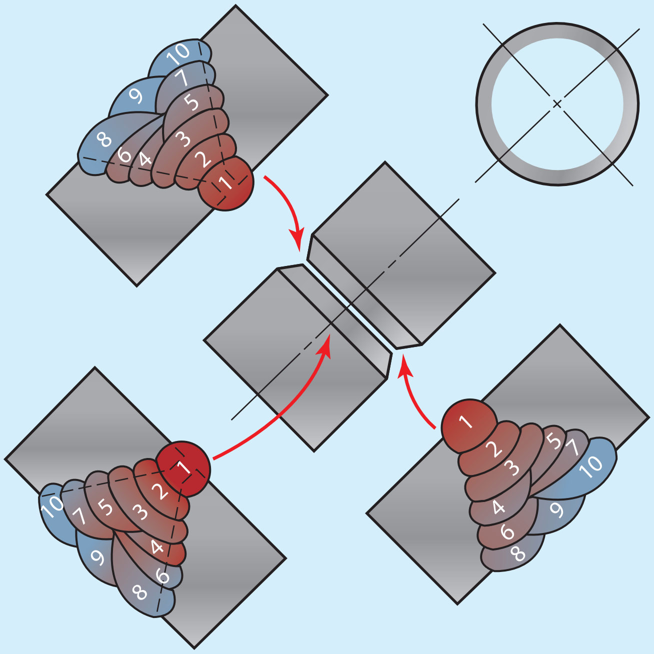


FIGURE 6-40 6G welding bead sequence.

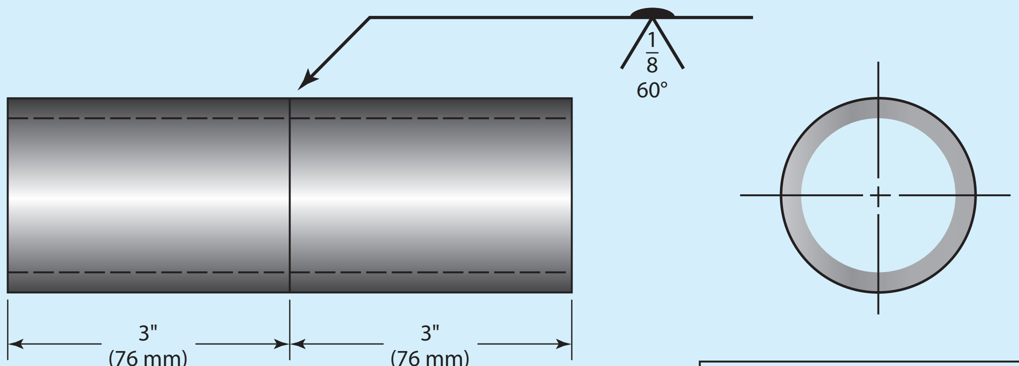
Bend Test:
The weld is to be mechanically tested only after it has passed the visual inspection. Be sure that the test specimens are properly marked to identify the welder, the position, and the process.

Specimen Preparation:
The weld must be prepared for bend testing in accordance with the AWS Specimen Preparation Criteria.

Acceptance Criteria for Bend Test:
The bent specimen must not exceed any of the acceptable limits of discontinuities as listed in the AWS Acceptance Criteria for Bend Test.

Repair:
No repairs of defects are allowed.

Sketches:



Welding Principles and Applications	
MATERIAL: 3 IN. – 8 IN. SCHEDULE 40 CARBON STEEL PIPE	
PROCESS: E6010 OR E6011 ROOT PASS E7018 FILLER AND COVER PASSES	
NUMBER: PRACTICE 6-6	DRAWN BY: ELIJAH DUBOIS

Paperwork:
Compete a "Bill of Materials," "Time Sheet," and "Performance Qualification Test Record" in Appendix I or as provided by your instructor.

Complete a copy of the Face-Bend and Root-Bend Test Results report form listed in Appendix I or provided by your instructor.

PRACTICE 6-7 AWS SENSE

Welding Procedure Specification (WPS)

Welding Procedures Specifications No.: PRACTICE 6-7.

Title:
Welding SMAW of pipe to pipe.

Scope:
This procedure is applicable for V-groove pipe with or without a back ring within the range of 6 in. (150 mm) schedule 80 through 8 in. (203 mm) schedule 80.

Welding may be performed in the following positions: 6G (AWS SENSE Level II).

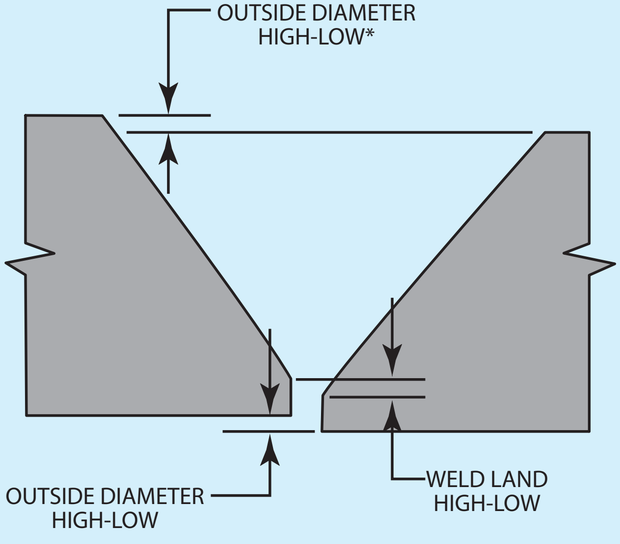
Base Metal:
The base metal shall conform to Carbon Steel M-1/P/1S-1, Group 1 or 2.

Backing Ring:
Backing ring to suit diameter and nominal wall thickness of pipe.

Filler Metal:
The filler metal shall conform to AWS specification No. E7018 for root, fill, and cover passes from AWS specification A5.1. This filler metal falls into F-numbers F4 and A-number A-1.

Shielding Gas:
The shielding gas, or gases, shall conform to the following compositions and purity: N/A.

Joint Design and Tolerances:



*MAXIMUM PIPE JOINT OFFSET, HIGH-LOW 1/8" (3 mm)

Preparation of Base Metal:
All workmanship parts must be prepared according to the AWS Workmanship Standard for Preparation of Base Metal.

Electrical Characteristics:
The current shall be AC or DCEP. The base metal shall be on the work lead or negative side of the line.

Preheat:
The parts must be heated to a temperature higher than 70°F (21°C) before any welding is started.

Backing Gas:
N/A.

Welding Technique:
Tack weld the pipes together; there should be an approximately 1/8-in. (3-mm) root gap between the pipe ends. Use E7018 arc welding electrodes to make a root pass to fuse the pipe ends together. Clean the slag from the root pass and use either a hot pass or grinder to remove any trapped slag.

Using the E7018 arc welding electrodes, make a series of filler welds in the groove until the joint is filled. Figure 6-40 shows the recommended location sequence for the weld beads for the 6G position.

Interpass Temperature:
The plate should not be heated to a temperature higher than 350°F (175°C) during the welding process. After each weld pass is completed, allow it to cool; the weldment must not be quenched in water.

Cleaning:
The slag can be chipped and/or ground off between passes but can only be chipped off of the cover pass.

Visual Inspection Criteria for Entry-Level Welders:
The weld must pass a visual inspection by the instructor or test supervisor based on the AWS Visual Inspection Criteria.

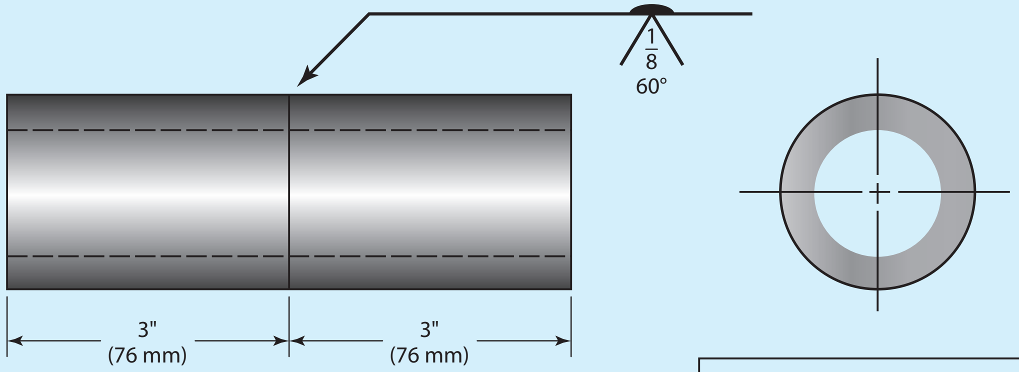
Bend Test:
The weld is to be mechanically tested only after it has passed the visual inspection. Be sure that the test specimens are properly marked to identify the welder, the position, and the process.

Specimen Preparation:
The weld must be prepared for bend testing in accordance with the AWS Specimen Preparation Criteria.

Acceptance Criteria for Bend Test:
The bent specimen must not exceed any of the acceptable limits of discontinuities as listed in the AWS Acceptance Criteria for Bend Test.

Repair:
No repairs of defects are allowed.

Sketches:



Welding Principles and Applications	
MATERIAL: 6 IN. – 8 IN. SCHEDULE 80 CARBON STEEL PIPE	
PROCESS: E7018 FOR ALL WELD PASSES	
NUMBER: PRACTICE 6-7	DRAWN BY: ELIJAH DUBOIS

POOR FIT-UP

Ideally, all welding will be performed on joints that are properly fitted. Most welds produced to a code or standard are properly fitted. Repair, prototype, and job shop welding, however, may not be cut and fitted properly. These welds must be performed under less than ideal conditions, but they still must be strong and have a good appearance.

Making a good weld on a poorly fitted joint requires some special skills. These welds also require a good welder, one whose skill is developed. A skilled welder can watch the molten weld pool and knows how to correct for problems before they develop into disasters. The welder must be able to read the molten weld pool correctly to make needed changes in amperage, current, electrode movement, electrode angle, and timing.

The amperage setting may have to be adjusted up or down by only a few amperes to make the necessary changes in molten weld pool size. Adjusting the machine is often preferable to lengthening the weave pattern excessively. The current may be changed from AC to DCSP or DCRP to vary the amount of heat input to the molten weld pool. Some electrodes can operate better than other electrodes with lower amperages on some currents. The current will also alter the forcefulness of some electrodes.

The "U," "J," and straight step patterns are usually the best to use, but they should not be moved more than required to close the gap or opening. On some poor-fitting joints, it is necessary to break and restart the arc to keep the molten weld pool under control. This will result in a weld with porosity, slag inclusions, and other defects. But it is often better to have a poor weld than to have no weld. A poor root weld can be capped with a sound weld to improve joint strength.

Changing the electrode angle from leading to trailing improves poor fit. Sometimes a very flat angle will also help. The time interval that the electrode is moved into and out of the molten weld pool is critical in maintaining weld control. Returning to a molten weld pool too often or too soon can cause the molten weld pool to drop out of the joint. In most cases, a welder should return to the molten weld pool only after it has started to cool.

On some joints, it is possible to make stringer beads on both sides of the joint until the gap is closed, **Figure 6-41**.

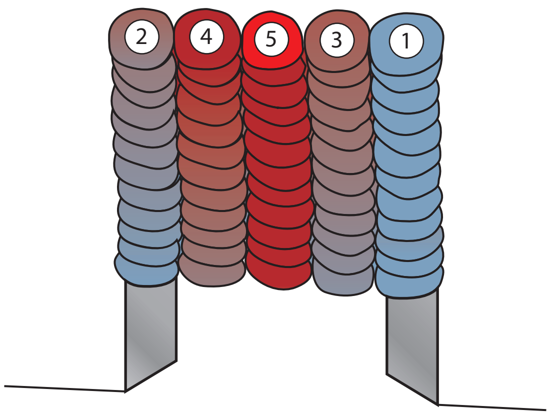


FIGURE 6-41 Technique for bridging a gap.

Note that the beads are made alternately from the edges of the joint to the center. Welds made in this manner can have good weld soundness and strength, but they require more time to complete.

PRACTICE 6-8

Single V-Groove Open Root Butt Joint with an Increasing Root Opening

For this practice, you will need a properly set up and adjusted arc welding machine, proper safety protection, E6010 or E6011 and E7018 arc welding electrodes with a 1/8 in. (3 mm) diameter, and two or more pieces of mild steel plate 3/8 in. (10 mm) thick × 4 in. (102 mm) wide × 12 in. (305 mm) long. You will weld a single V-groove open root butt joint that has a poor fit-up, starting from the close end.

Tack weld the plates together with a root opening of 1/8 in. (3 mm) at one end and 1/2 in. (13 mm) at the other end, **Figure 6-42**. Using the E6010 or the E6011 electrode, start the root pass at the narrow end and weld to the other end. As the root pass progresses along the widening root gap, care must be taken to maintain molten weld pool control. The "J" or "U" weave pattern works best with low current settings. Long time intervals for electrode movements will give the best weld control.

When the root pass is completed, clean the weld and make a hot pass to burn out any trapped slag. Finish the weld with filler passes using the E7018 electrode. Cool, chip, and inspect the weld for uniformity and defects. Repeat these welds until you can consistently make welds free of defects. Turn off the welding machine and clean your work area when you are finished welding.

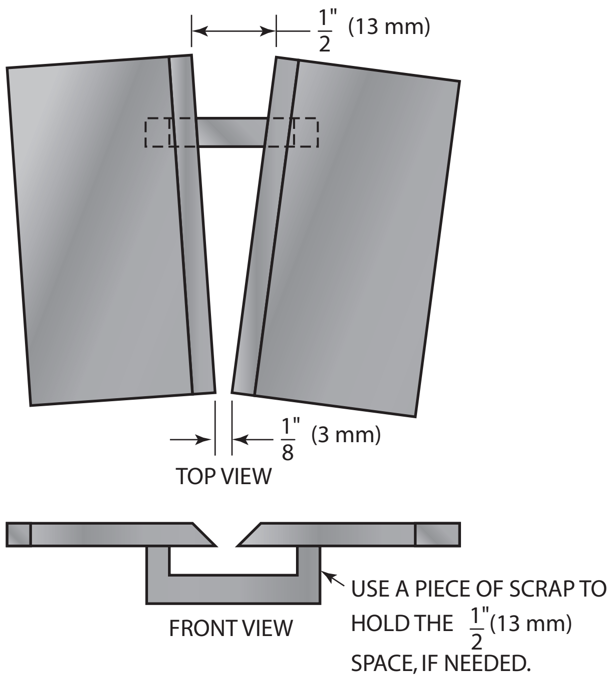


FIGURE 6-42 Uneven joint practice weld plate setup.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 6-9

Single V-Groove Open Root Butt Joint with a Decreasing Root Opening

Using the same setup, equipment, and materials as described in Practice 6-8, you will weld a single V-groove open root butt joint that has a poor fit-up, starting from the wide end.

As in Practice 6-8, tack weld the plates together with a root opening of 1/8 in. (3 mm) at one end and 1/2 in. (13 mm) at the other end. Using the E6010 or E6011 electrode, start welding the root pass at the wide end. Both sides of the joint must be built up until it is possible to get the metal to flow together. The "J" or "U" weave pattern works best to control the bead.

When the root pass is completed, make a hot pass to clean out any trapped slag before making the filler passes with the E7018 electrode. After the weld is completed, cool, chip, and inspect it for uniformity and defects. Repeat these welds until you can consistently make welds free of defects. Turn off the welding machine and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

Summary

Grooved welds on approximately 1/2-in. (13-mm) -thick plate are the most common test plates given to new welding applicants. Groove welds are used by many companies as the base welding skills performance test requirement for employment. The vertical and overhead positions are the most commonly used for the test. It is often assumed in the welding industry that a uniform weld free of visual defects will successfully pass destructive testing. This assumption has great basis in fact because, in most cases, such a weld reflects the welder's skills required to produce quality welds; therefore, in many cases, applicant test welds are evaluated only by the weld shop foreman or supervisor for visual defects. For this reason, you should always attempt to make your welds as uniform in appearance as possible. Learning how to make a "pretty" groove weld can often mean the difference between successfully earning the job and losing out to another applicant.

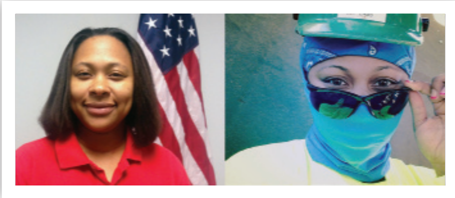
Review

1. What is the first weld bead of a multiple pass weld called?
2. What is the purpose of using ceramic backup tapes on groove welds?
3. How can discontinuities in the root face be removed?
4. Describe the motion of the electrode in key hole welding.
5. What is the purpose of placing an assembled test plate on an anvil and striking it with a hammer?
6. If the key hole becomes smaller and smaller, what can be done to increase the molten weld pool size and maintain the key hole?
7. What is the purpose of a hot pass?
8. What are the best ways to remove slag between filler weld passes?
9. What is the last weld bead on a multipass weld called?
10. What is the purpose of grooving a joint before welding on thick plate?
11. After a weld is back gouged and a groove is formed, what should be done?
12. When stopping an SMA welding bead on a pipe, what should be done to make restarting it more uniform?
13. What is the purpose of preheating metal before it is welded?
14. What is the purpose of postheating the metal after welding?
15. What is interpass temperature?
16. The AWS Visual Inspection Criteria allows one small porosity per _____ inches of weld.
17. What is the difference between a transverse face bend and a transverse root bend?
18. What changes can be made to successfully make a weld in a poorly fitted joint?

Section 3

Cutting and Gouging

Success Story



My name is Shakirah Harrell. I was born in Newark, New Jersey and raised in the little town of Powellsville, North Carolina. I graduated from Hertford County High School in Ahoskie, North Carolina. As a single young parent, I needed to find a career field that would support my family, so I moved to Hampton, Virginia. I started my welding career at the age of 23.

At that time, the only thing I knew about welding was that it was a good paying job. I applied at Northrop Grumman, a shipyard in Newport News, Virginia, and began my training as a welder. To help support my family, I worked as a grocery store manager in the morning and welder at night. After one year in the field as a 3rd class welder, I got accepted into the apprenticeship program. I spent the next five years learning the welding trade while still being able to support my family. I graduated from the apprenticeship program in 2008.

Then I decided to pursue another angle in the welding trade. I got hired at a local welding school where I began instructing basic welding during the day while working on my Bachelor's Degree in business management at night and online. After only a few months, I was asked to take a position at the school as the welding coordinator for the entire program.

After four years, I missed welding and the money I would make, so I decided to go back into the field as a contractor at another local shipyard in Norfolk, Virginia. Over the next few years, I followed welding opportunities across other parts of the United States. I was a structural welder at an ethanol plant project in Liberal, Kansas. Following that, I moved to Freeport, Texas, took a refresher pipe welding course offered by Fluor, and started working on a chemical plant project for Dow Chemical Company.

After being away from Virginia for so many years, I was homesick and decided to go back to Virginia; but as a result of the downturn in the economy, I was not able to find a good high-paying job, so I moved back to Texas. I am currently a welding instructor at Tulsa Welding School and Technology Center at the Houston campus.

Welding has been a great career for me and a skill that has provided for my family. My oldest son has joined the United States Navy, one of the others is a high school senior, and the youngest is a high school junior. I'm proud to be a welder, I'm proud of my kids, and proud of the life that welding has provided for us.

Chapter 7

Flame Cutting

OBJECTIVES

After completing this chapter, the student should be able to

- describe the eye protection that must be used for flame cutting.
- discuss the oxyfuel gas cutting process including fuel gases, metals, regulators, torches, and cutting tips.
- demonstrate how to safely set up, light, adjust, and maintain a cutting torch.
- demonstrate how to make clean slag-free cuts in various material thicknesses both manually and using a cutting machine.
- demonstrate how to make a square cut on pipe in the horizontal rolled position, the horizontal fixed position, and the vertical position.

KEY TERMS

combination welding and cutting torch
coupling distance
creep
cutting lever
cutting tips
diaphragm
drag
drag lines
equal-pressure torches
flashback arrestor
hard slag
high-speed cutting tip
injector chamber
kindling point
kindling temperature
leak-detecting solution
line pressure drop
machine cutting torch
mixing chamber
MPS gases
orifice
oxyacetylene hand torch
oxyfuel gas cutting (OFC)
preheat flame
preheat holes
regulator gauges
regulators
safety disc
safety release valve
seat
Siamese hose
slag
soapstone
soft slag
tip cleaners
two-stage regulators
venturi
working pressure

INTRODUCTION

Oxyfuel gas cutting (OFC) is a group of oxygen cutting processes that use heat from an oxyfuel gas flame to raise the temperature of the metal to its **kindling temperature** before a high-pressure stream of oxygen is directed onto the metal, causing it to be cut. The kindling temperature of a material is the temperature at which rapid oxidation (combustion) can begin. This cutting process is grouped and identified by the type of fuel gas used with oxygen to produce the preheat flame. Oxyfuel gas cutting is most commonly performed with oxyacetylene cutting (OFC-A). **Table 7-1** lists a number of other fuel gases used for OF cutting. MPS (MAPP) and propane gases are increasingly being used for cutting and rivals acetylene's popularity in some areas of the fabrication.

More people use the oxyfuel cutting torch than any other welding process. The cutting torch is used by workers in virtually all areas, including manufacturing, maintenance, automotive repair, railroad, farming, and more. It is unfortunately one of the most commonly misused processes. Most workers know how to light the torch and make a cut, but their cuts are of very poor quality. Often, in addition to making bad cuts, they use unsafe torch techniques. A good oxyfuel cut not only should be straight and square but also should require little or no postcut cleanup. Excessive postcut cleanup results in extra cost, which is an expense that cannot be justified.

Manual, mechanized, and automatic OFC processes are used in industry. Hand-controlled, manual cutting is done in short-run production and one-of-a-kind fabrication, as well as in demolition and scrapping operations. Manual cutting is also used in the field for steel construction. Mechanized or automatic cutting is widely used in production work where a large number of identical cuts are made over and over or where very precise cuts are required. In mechanized or automatic cutting, more than one cutting head may be mounted so several cuts can be made at the same time.

Various oxyfuel cutting specialties are found on the job, including flame cutting, gouging, beveling, scarfing, and the operation of an automated cutting machine. In addition to these cutting jobs, some welders work dismantling scrap metal, such as scrap autos or construction demolition.

Fuel Gas	Flame (Fahrenheit)	Temperature* (Celsius)
Acetylene	5589°	3087°
MAPP®	5301°	2927°
Natural gas	4600°	2538°
Propane	4579°	2526°
Propylene	5193°	2867°
Hydrogen	4820°	2660°

*Approximate neutral oxyfuel flame temperature.

TABLE 7-1 Fuel Gases Used for Flame Cutting

METALS CUT BY THE OXYFUEL PROCESS

The process will work easily on any reactive metal that will rapidly oxidize at an elevated temperature. It is most often used to cut low-carbon steels with carbon contents up to 0.3%. Little or no oxides are left on the metal following a good cut, so it can be easily welded. A few reactive nonferrous metals, such as titanium, zinc, and magnesium, can also be cut. But these metals seldom are cut with the OFC process because of the extensive postcut cleanup required and they may give off excessive hazardous fumes.

Any metal that requires preheating for welding, such as high alloy and high alloy carbon steels, should also be preheated before cutting. Failing to preheat some high-strength alloys before cutting can result in a very thin hardness zone on the cut surface. This hardness zone can cause cracks to start in the finished part. If high-strength steel flame-cut parts are to be bent or formed, the hardened edge may cause cracks to form. These surface cracks can actually cause the part to fracture and fail.

OFC cannot be used to cut nonreactive metals such as stainless steel, cast iron, brass, copper, aluminum, and almost all other nonferrous metals.

THE CHEMISTRY OF A CUT

The oxyfuel gas cutting torch works by first preheating the metal to its kindling temperature before a high-pressure stream of pure oxygen is turned on to rapidly oxidize or burn the metal away. **Kindling point** and **kindling temperature** are two terms that have the same meaning; they refer to the lowest temperature at which a material will combust or start burning. The kindling temperature of most steel in pure oxygen is between 1600° and 1800°F (870°C to 900°C), which is a dull red color.

The OFC process is sometimes referred to as flame cutting, torching, or burning. For example someone may be asked, "Burn that piece off" or "Go burn me that part." The term burning is accurate because you are actually burning away the metal. Combustion is a chemical reaction with heated iron (Fe) and high-pressure oxygen (O). The oxygen forms an iron oxide, primarily Fe_3O_4, that is light gray in color. As with any combustion process, heat is produced as the metal is burned. This heat helps carry the cut along. On thick pieces of metal, once a small spot starts burning (being cut), the heat generated helps the cut continue quickly through the metal.

EYE PROTECTION FOR FLAME CUTTING

The National Bureau of Standards has identified proper filter plates and uses. The recommended filter plates are identified by shade number and are related to the type of cutting operation being performed.

Type of Cutting Operation	Hazard	Suggested Shade Number
Light cutting, up to 1 in.	Sparks, harmful rays,	3 or 4
Medium cutting, 1-6 in.	molten metal, flying	4 or 5
Heavy cutting, over 6 in.	particles	5 or 6

TABLE 7-2 A General Guide for the Selection of Eye and Face Protection Equipment

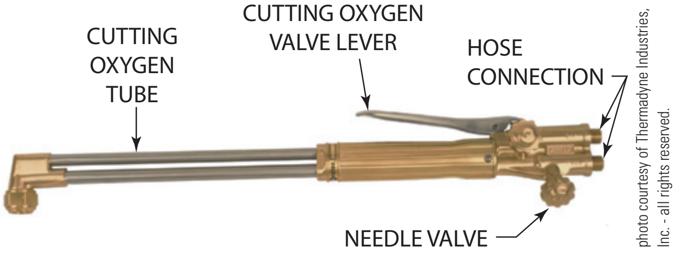


FIGURE 7-1 Dedicated oxyfuel cutting torch.

Goggles or other suitable eye protection must be used for flame cutting. Goggles should have vents near the lenses to prevent fogging. Cover lenses or plates should be provided to protect the filter lens. All lens glass should be ground properly so that the front and rear surfaces are smooth. Filter lenses must be marked so that the shade number can be readily identified, **Table 7-2**.

CUTTING TORCHES

The **oxyacetylene hand torch** is the most common type of oxyfuel gas cutting torch used in industry. The hand torch, as it is often called, may be either a part of a **combination welding and cutting torch** set or a cutting torch only, **Figure 7-1**. The combination welding and cutting torch offers more flexibility because a cutting head, welding tip, or heating tip can be attached quickly to the same torch body, **Figure 7-2**. Combination torch sets are often used in schools, automotive repair shops, auto body shops, and small welding shops or with any job where flexibility in equipment is needed. A cut made with either type of torch has the same quality; however, the dedicated cutting torches are usually longer and have larger gas flow passages than the combination torches. The added length of the dedicated cutting torch helps keep the operator farther away from the heat and sparks and allows thicker material to be cut.

Oxygen is mixed with the fuel gas to form a high-temperature preheating flame. The two gases must be completely mixed before they leave the tip and create the flame. Two methods are used to mix the gases. One method uses a **mixing chamber**, and the other method uses an **injector chamber**.

The mixing chamber may be located in the torch body or in the tip, **Figure 7-3**. Torches that use a mixing

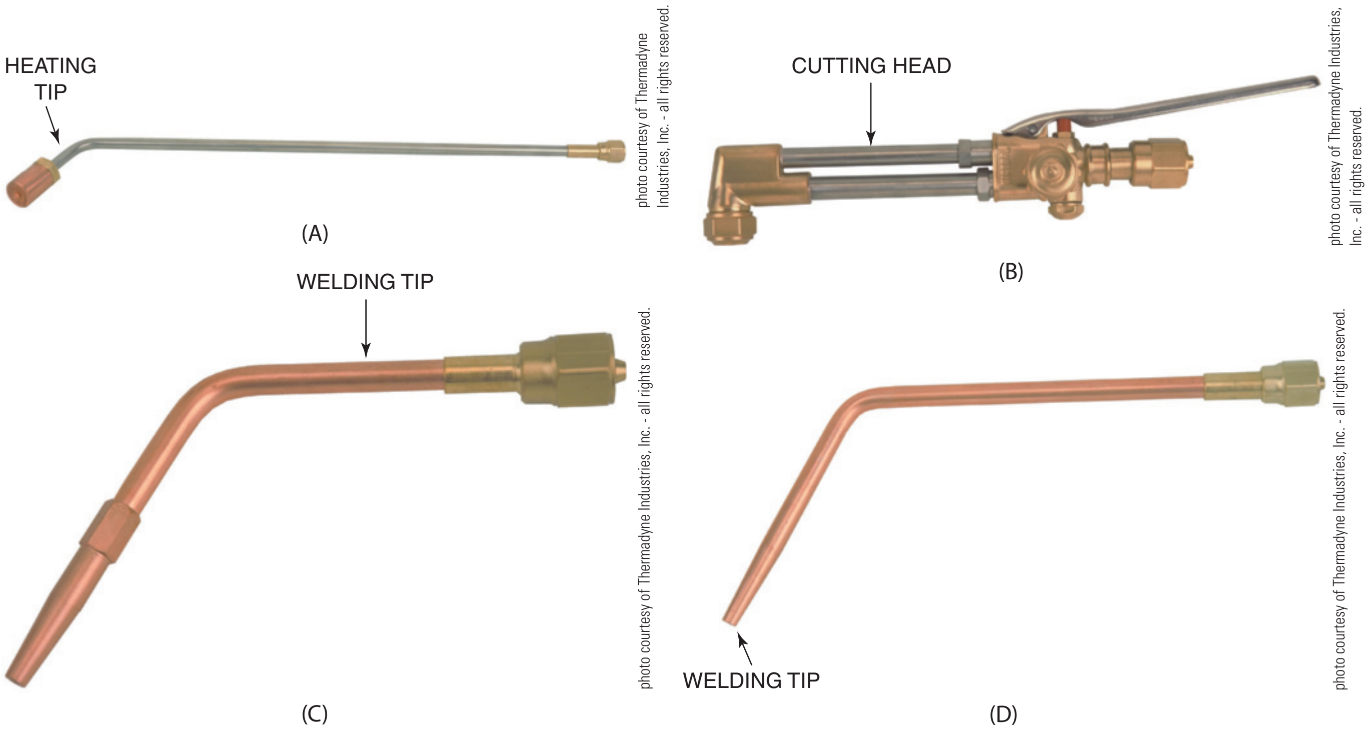


FIGURE 7-2 The attachments that are used for heating, cutting, welding, or brazing make the combination torch set flexible. (A) Heating tip, (B) cutting head, (C) two-piece welding tip, and (D) single-piece welding tip.

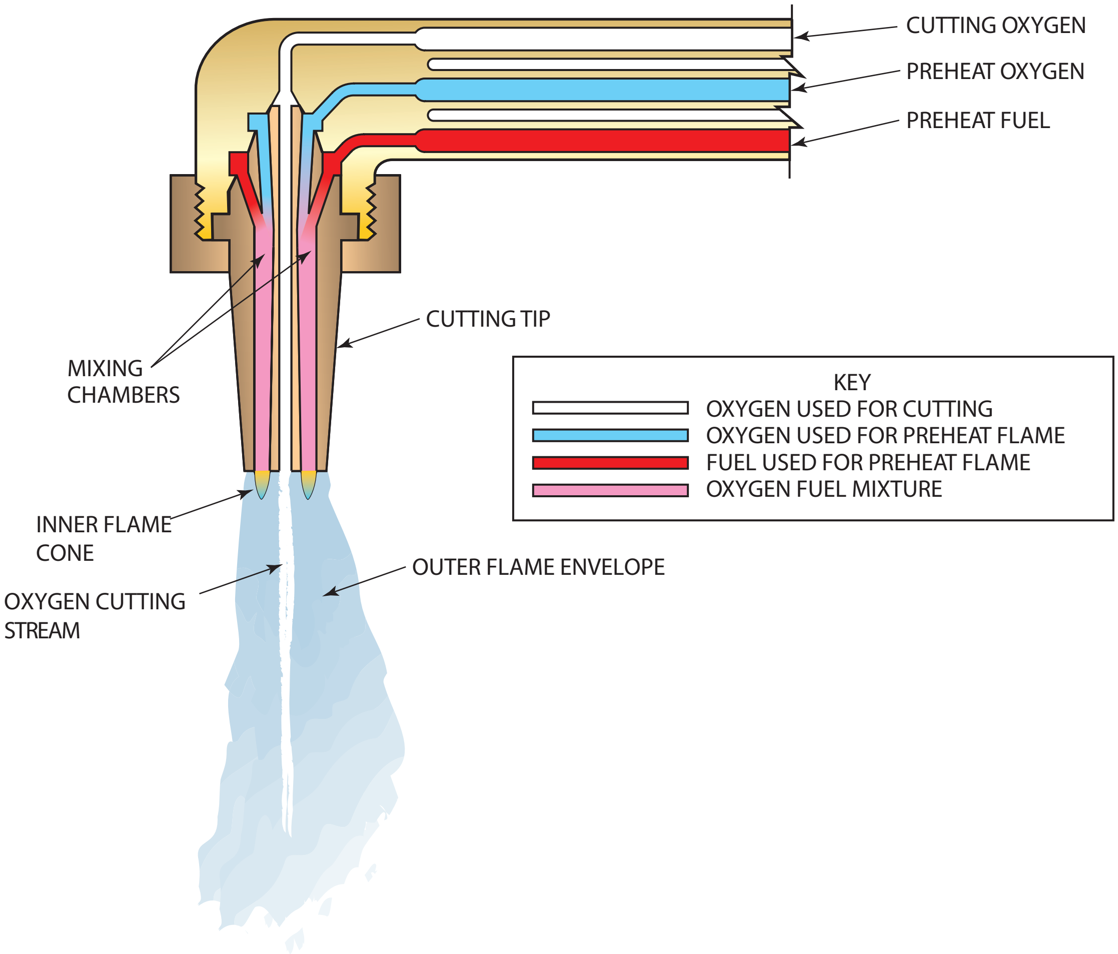


FIGURE 7-3 A mixing chamber located in the tip.

chamber are known as **equal-pressure torches** because the gases must enter the mixing chamber under the same pressure. The mixing chamber is larger than both the gas inlet and the gas outlet. This larger size causes turbulence in the gases, resulting in the gases mixing thoroughly.

Injector torches will work with both equal gas pressures and low fuel gas pressures, **Figure 7-4**. The injector allows the oxygen to draw the fuel gas into the chamber even if the fuel gas pressure is as low as 6 oz/in.^{2} (26 g/cm^2). The injector works by passing the oxygen through a **venturi**, which creates a low-pressure area that pulls the fuel gases in and mixes them together. An injector-type torch must be used if a low-pressure acetylene generator or low-pressure residential natural gas is used as the fuel gas supply.

The cutting head may hold the cutting tip at a right angle to the torch body or it may be held at a slight angle. Torches with the tip slightly angled are easier for the welder to use when cutting flat plate. Torches with a right-angle tip are easier for the welder to use when cutting pipe, angle iron, I-beams, or other uneven material shapes. Both types of torches can be used for any type of material being cut, but practice is needed to keep the cut square and accurate.

The location of the **cutting lever** may vary from one torch to another, **Figure 7-5**. Most cutting levers pivot from the front or back end of the torch body. Personal preference will determine which one the welder uses.

A **machine cutting torch**, sometimes referred to as a line burner, operates in a manner similar to that of a hand-cutting torch. The machine cutting torch may require two oxygen regulators, one for the preheat oxygen and the other for the cutting oxygen stream. The addition of a separate cutting oxygen supply allows the flame to be more accurately adjusted. It also allows the pressures to be adjusted during a cut without disturbing the other parts of the flame. Various machine cutting torches are shown in **Figure 7-6**, **Figure 7-7**, and **Figure 7-8**.

CUTTING TIPS

Most **cutting tips** are made of copper alloy, but some tips are chrome. Chrome plating prevents spatter from sticking to the tip, thus prolonging its usefulness. Tip designs

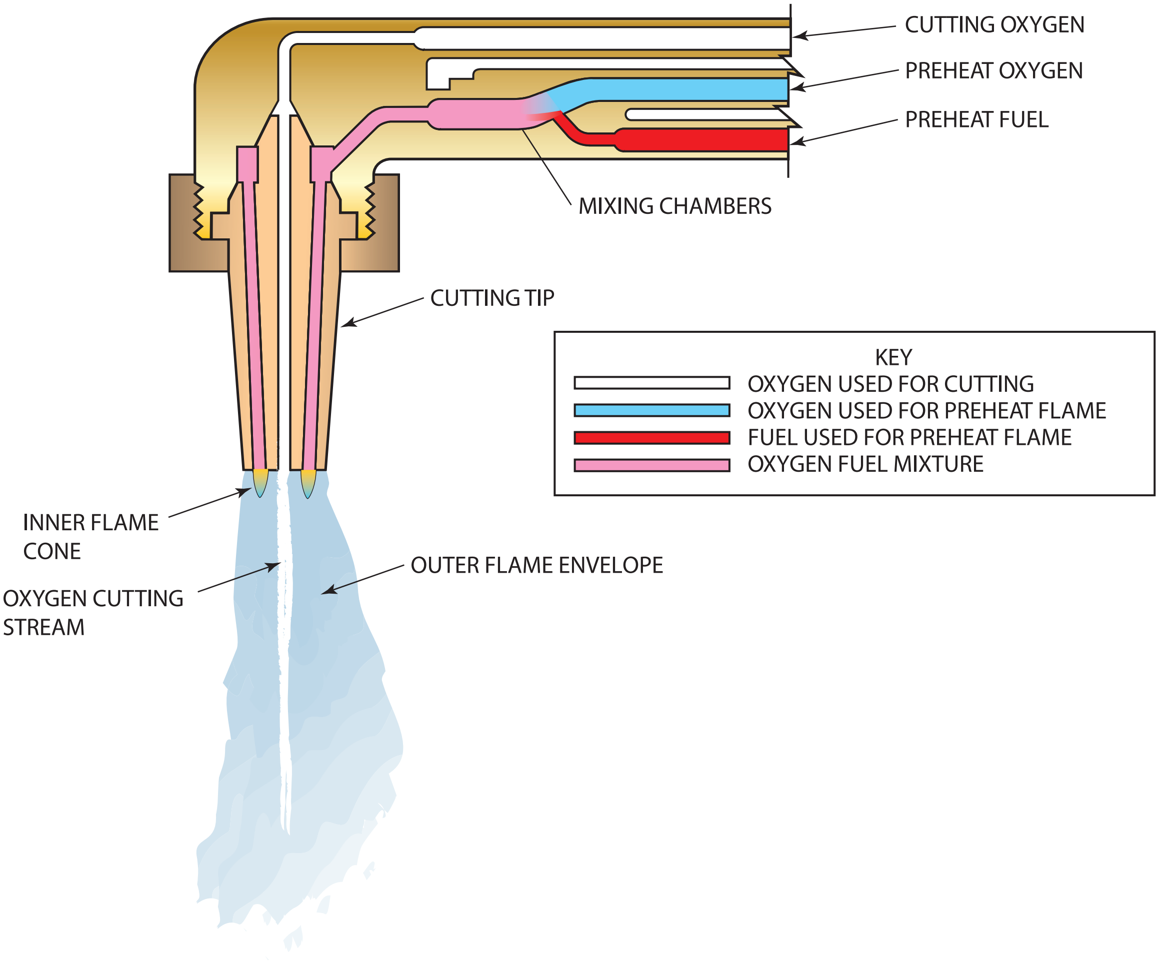


FIGURE 7-4 Injector mixing torch.

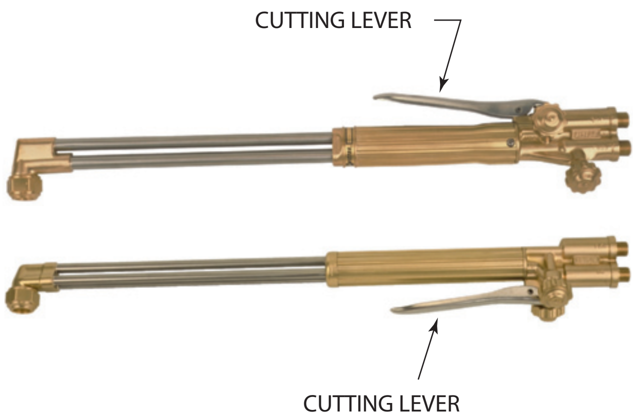
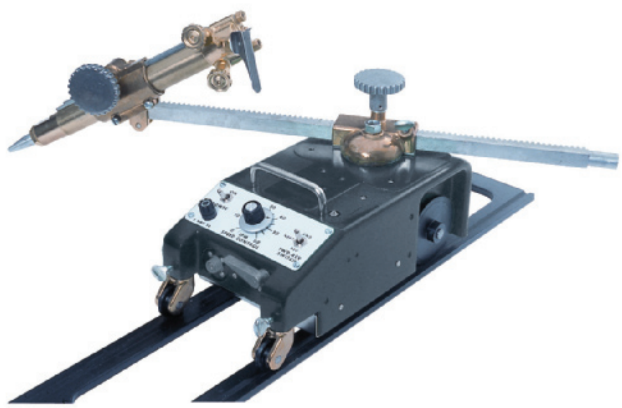


photo courtesy of Thermadyne Industries, Inc. - all rights reserved.

photo courtesy of Thermadyne Industries, Inc. - all rights reserved.

FIGURE 7-5 The cutting lever may be located on the front or back of the torch body.



Courtesy of ESAB Welding & Cutting Products

FIGURE 7-6 Portable flame-cutting machine.

change for the different types of uses and gases, and from one torch manufacturer to another, **Figure 7-9**.

Tips for straight cutting are either standard or high-speed, **Figure 7-10**. The **high-speed cutting tip** is designed to allow a higher cutting oxygen pressure, which allows the torch to travel faster. High-speed tips are also available for different types of fuel gases.

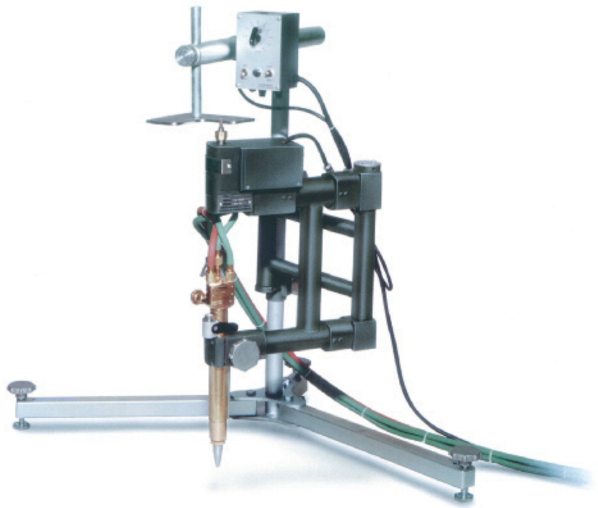
The diameter, or size of the center cutting orifice, determines the thickness of the metal that can be cut. A larger diameter oxygen orifice is required for cutting thick metal.

Courtesy of ESAB Welding & Cutting Products

FIGURE 7-7 Multiple head cutting machine.

Larry Jeffus

FIGURE 7-9 Different cutting torch seals for different manufacturers' torches.



Courtesy of ESAB Welding & Cutting Products

FIGURE 7-8 Portable cutting machine for highly complex shapes.

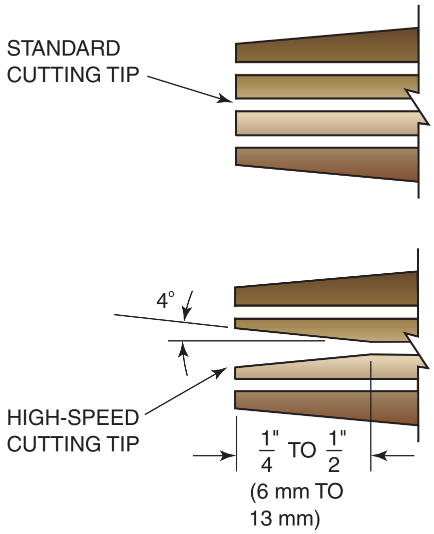


FIGURE 7-10 Comparison of standard and high-speed cutting tips.

There is no standard numbering system for sizing cutting tips. Each manufacturer uses its own system. Some systems are similar; some are not. **Table 7-3** lists several manufacturers' tip numbering systems. As a way of comparing the size of one manufacturer's tip size to another, the center hole diameter in inches is given below the tip number. For example, in Table 7-3 you can see that Airco's tip number 00 has a center orifice size equal to a number 70 drill size. In Table 7-3 you can see that this cutting tip is designed for cutting metal approximately 1/8 in. (3 mm) thick. Other manufacturer tip numbers designed for this thickness have the following numbers: 000, 00, 1/4, 2, and 3.

Manufacturer	Metal Thickness, Inches (mm)										
	1/8 (3)	1/4 (6)	1/2 (13)	3/4 (19)	1 (24)	1 1/2 (37)	2 (49)	2 1/2 (61)	3 (74)	4 (98)	5 (123)
Cutting orifice drill number	70	68	60	56	54	53	50	47	45	39	31
Airco	00	0	1	1	2	2	3	4	4	5	6
ESAB	1/4	1/4	1/2	1 1/2	1 1/2	1 1/2	4	4	4	4	8
Harris	000	00	0	1	1	2	2	3	3	3	4
Oxweld	2	3	4	6	6	6	8	8	8	8	8
Purox	3	3	4	4	5	5	7	7	7	7	9
Smith	00	0	1	2	2	3	3	4	4	4	5
Victor	000	00	0	1	2	2	3	4	4	5	6

TABLE 7-3 Comparison of Some Manufacturers' Oxyacetylene Cutting Tip Identifications

Tip Size	Metal Thickness, Inches (mm)										
	1/8 (3)	1/4 (6)	1/2 (13)	3/4 (19)	1 (24)	1 1/2 (37)	2 (49)	2 1/2 (61)	3 (74)	4 (98)	5 (123)
Cutting orifice drill number	70	68	60	56	54	53	50	47	45	39	31
WYPO tip cleaner number*	10	10	15	18	22	24	26				
Campbell Hausfeld tip cleaner number*	3	3	6	9	10	11	12				
Oxygen pressure, psi**	20 25	20 25	25 30	30 35	35 40	35 40	40 45	40 45	40 45	45 55	45 55
Oxygen pressure, kPa**	140 170	140 170	170 200	200 240	240 275	240 275	275 310	275 310	275 310	310 380	310 380
Acetylene pressure, psi**	3 5	3 5	3 5	3 5	3 5	3 5	4 8	4 8	5 11	6 13	8 14
Acetylene pressure, kPa**	20 35	20 35	20 35	20 35	20 35	20 35	30 55	30 55	35 75	40 90	55 95

*There is no standard numbering system for tip cleaners, so numbers can differ from one manufacturer to another.
**Tip size and pressures are approximate. Use the manufacturer's specification for equipment being used when available.

TABLE 7-4 Center Cutting Orifice Size, Metal Thickness, and Gas Pressures for Oxyacetylene Cutting

Finding the correctly sized tip for a job can be confusing, especially if you are using the cutting unit for the first time. To make it easier to select a tip, you can use a standard set of **tip cleaners** to find the size of the center cutting orifice. **Table 7-4** lists the material thickness being cut with the tip cleaner size.

If the manufacturers' recommendations for gas pressure are not available, you can use Table 7-4 to find the approximate pressures to be used with the tip. Actual gas pressures vary, depending on a number of factors, such as the equipment manufacturer, the condition of the equipment, hose length, hose diameter, regulator size, and operator skill. In all cases, start out with the pressure recommended by the particular manufacturer of the equipment being used. Adjust the pressure to fit the job being cut.

A wide variety of tip shapes are also available for specialized cutting jobs. Each tip, of course, also comes in several sizes. Some tips are specialized for the kind of fuel gas being used. Different means are used to attach the cutting tip to the torch head. Some tips screw in; others have a push fitting.

In addition to those tips for torch hand cutting, different designs are used for mechanized and automated cutting tips. Mechanized and automated cutting tips are designed for high-speed cutting with high-speed oxygen flow.

Always choose the correct type and size of tip for the specific cutting job. Check the manufacturer's literature for tip size and type recommendations. Make sure the tip is designed for the type of fuel gas being used. Inspect the tip before using it. If the tip is clogged or dirty, clean the tip and clean out the orifices with the proper size tip cleaner. Check to make sure there is no damage to the threads. If the threads or the tapered seat is damaged, do not use the tip.

The amount of **preheat flame** required to make a perfect cut is determined by the type of fuel gas used and by the material thickness, shape, and surface condition. Materials that are thick, that are round, or that have surfaces covered with rust, paint, oil, and so on require more preheat flame, **Figure 7-11**.

Different cutting tips are available for each of the major types of fuel gases. The differences in the type or number of **preheat holes** determine the type of fuel gas to be used in the tip. **Table 7-5** lists the fuel gas and range of preheat holes or tip designs used with each gas. Acetylene is used in tips with one to six preheat holes. Some large acetylene cutting tips may have eight or more preheat holes.

CAUTION

Acetylene must be used in tips that are designed to be used with acetylene. If acetylene is used in tips designed for other fuel gases, then the tip may overheat, causing a backfire or even causing the tip to explode.

MPS gases are used in tips with eight preheat holes or in a two-piece tip that is not recessed, **Figure 7-12**. These gases have a slower flame combustion rate (see Chapter 26) than acetylene. For tips with fewer than eight preheat holes, there may not be enough heat to start a cut, or the flame may pop out when the cutting lever is pressed.

Propane and natural gas should be used in two-piece tips that are typically deeply recessed, Figure 7-12. The flame burns at such a slow rate that it may not stay lit on any other tip.

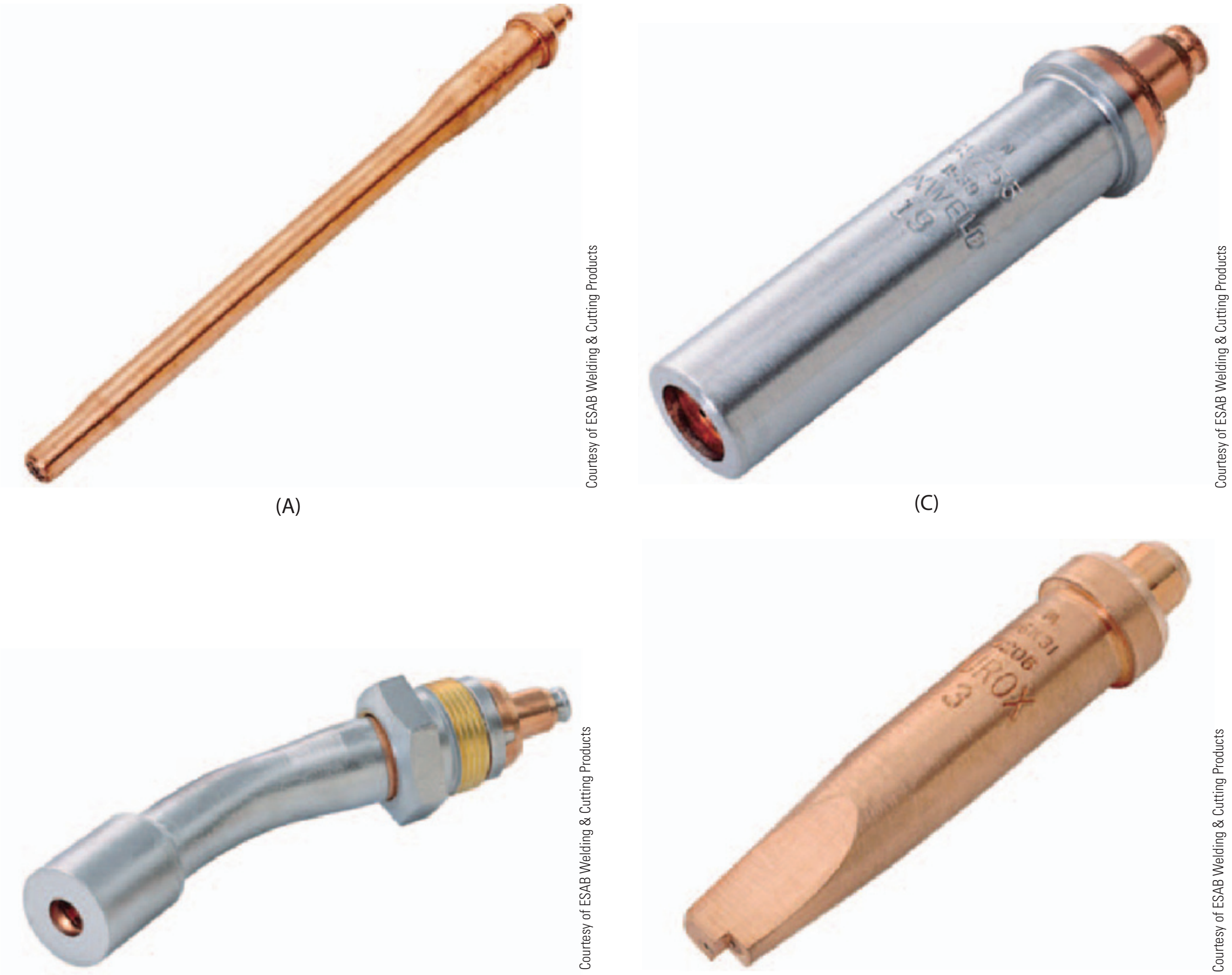


FIGURE 7-11 Special cutting tips come in a variety of shapes for many purposes. They can have different sizes and numbers of preheat holes. (A) 10-in.-long cutting tip, (B) water-cooled cutting tip, (C) replaceable end cutting tips, and (D) sheet metal cutting tip.

Fuel Gas	Number of Preheat Holes
Acetylene	One to six
MPS (MAPP)	Eight- to two-piece tip
Propane and natural gas	Two-piece tip

TABLE 7-5 Fuel Gas and Number of Preheat Holes Needed in the Cutting Tip

Some cutting tips have metal-to-metal seals. When they are installed in the torch head, a wrench must be used to tighten the nut. Other cutting tips have fiber packing seats to seal the tip to the torch. If a wrench is used to tighten the nut for this type of tip, then the tip seat may be damaged, **Figure 7-13**. A torch owner's manual should be checked or a welding supplier should be asked about the best way to tighten various torch tips.

When removing a cutting tip, if the tip is stuck in the torch head, tap the back of the head with a plastic hammer, **Figure 7-14**. Any tapping on the side of the tip may damage the seat.

To check the assembled torch tip for a good seal, turn on the oxygen valve and spray the tip with a leak-detecting solution, **Figure 7-15**.

CAUTION

Carefully handle and store the tips to prevent damage to the tip seats and to keep dirt from becoming stuck in the small holes.

If the cutting tip seat or the torch head seat is damaged, it can be repaired by using a reamer designed for the specific torch tip and head, **Figure 7-16**, or it can be sent out for repair. New fiber packings are available for tips with packings. The original leak-checking test should be repeated to be sure the new seal is good.

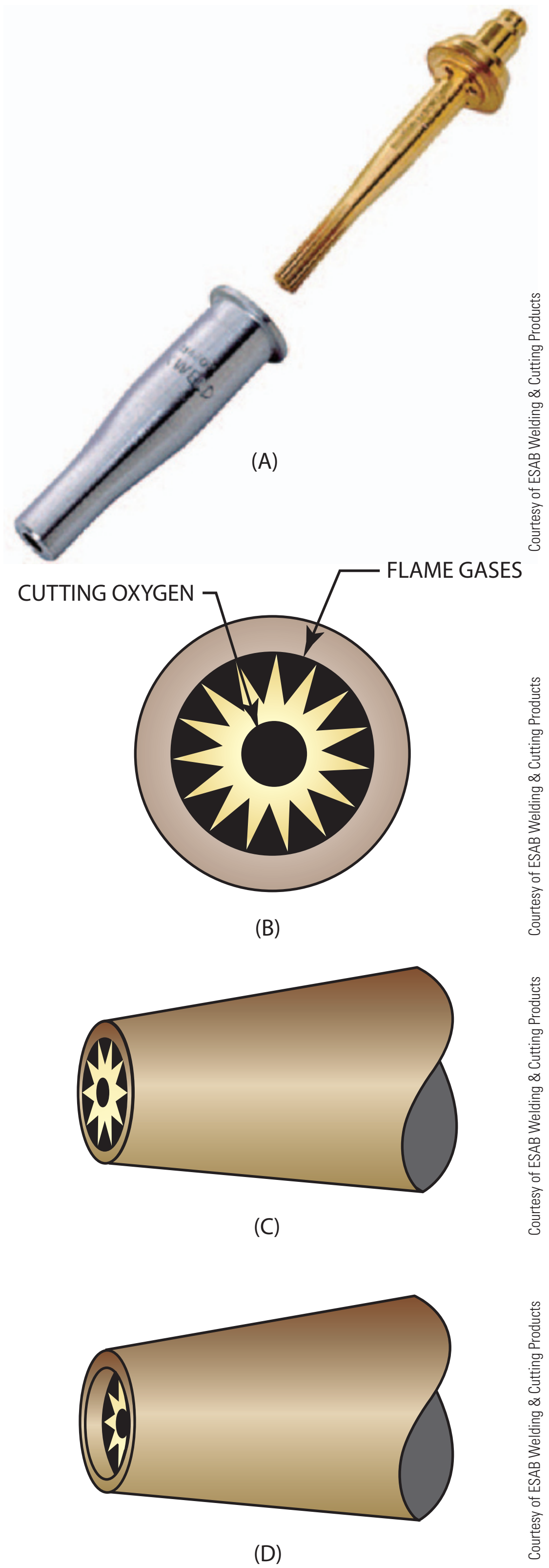


FIGURE 7-12 Parts of a two-piece cutting tip.

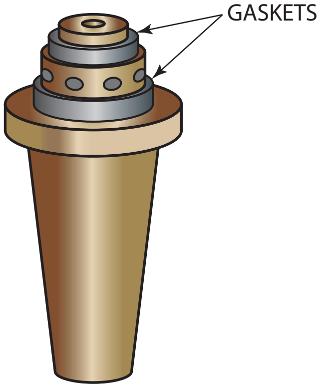


FIGURE 7-13 Some cutting tips use gaskets to make a tight seal.

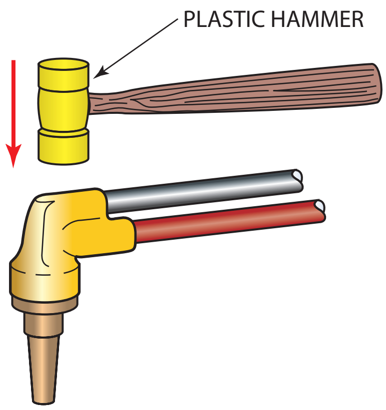


FIGURE 7-14 Tap the back of the torch head to remove a tip that is stuck. The tip itself should never be tapped.

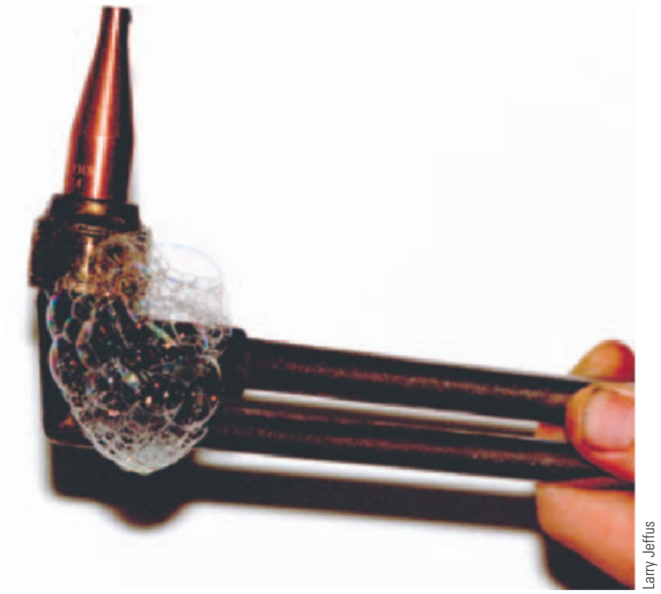


FIGURE 7-15 Checking a cutting tip for leaks.

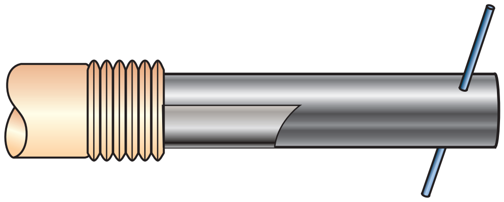


FIGURE 7-16 Damaged torch seats can be repaired by using a reamer.

PRESSURE REGULATORS

All pressure **regulators** reduce the high cylinder or system pressure to the proper lower working pressure. It is important for the regulator to keep the lower pressure constant over a range of flow rates. Some of the various types of pressure regulators are low-pressure regulators, high-pressure regulators, single-stage regulators, dual-stage regulators, cylinder regulators, manifold regulators, line regulators, and station regulators. Although they all work in the same way, they are not interchangeable.

CAUTION

Although all regulators work in the same way, they cannot be safely used interchangeably on different types of gas or for different pressure ranges without the possibility of a fire or an explosion.

REGULATOR OPERATION

A regulator works by holding the forces on both sides of a **diaphragm** in balance, **Figure 7-17**. As the adjusting screw is turned inward, it increases the force of a spring on the flexible diaphragm and bends the diaphragm away. As the diaphragm is moved, the small high-pressure valve is opened, allowing more gas to flow into the regulator. The gas pressure cancels the spring pressure, and the diaphragm returns back to its original position, closing the high-pressure valve, **Figure 7-18**.

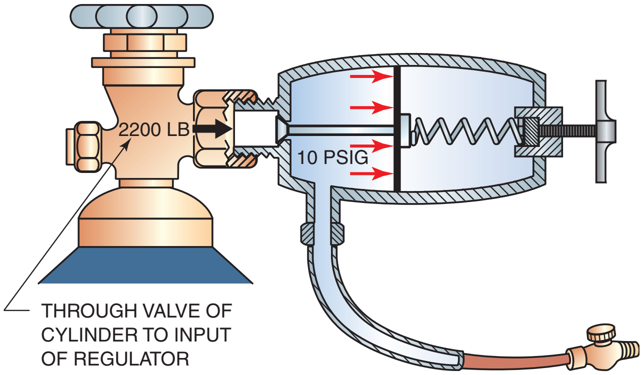


FIGURE 7-18 When the gas pressure against the flexible diaphragm equals the spring pressure, the high-pressure valve closes.

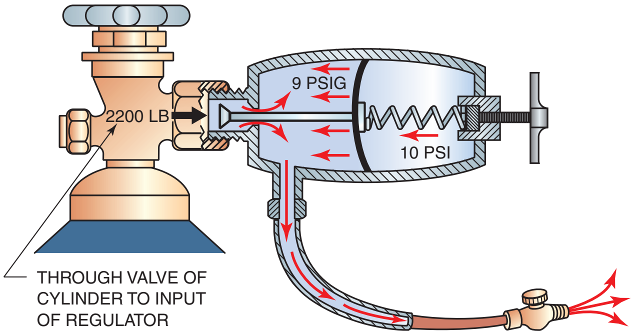


FIGURE 7-19 A drop in the working pressure occurs when the torch valve is opened and gas flows through the regulator at a constant pressure.

When the regulator is used, the gas pressure on the back side of the diaphragm is reduced, the spring again forces the valve open, and gas flows. The drop in the internal pressure can be seen on the working pressure gauge, **Figure 7-19**.

The size of a regulator determines its ability to hold the working pressure constant over a wider range of flow rates. **Two-stage regulators**, **Figure 7-20**, are able to keep the pressure constant at very low or high flow rates as the

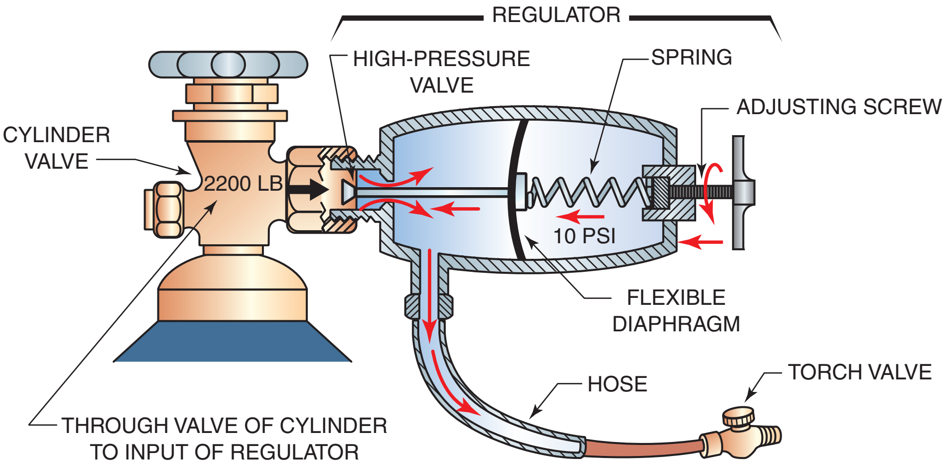


FIGURE 7-17 Force applied to the flexible diaphragm by the adjusting screw through the spring opens the high-pressure valve.

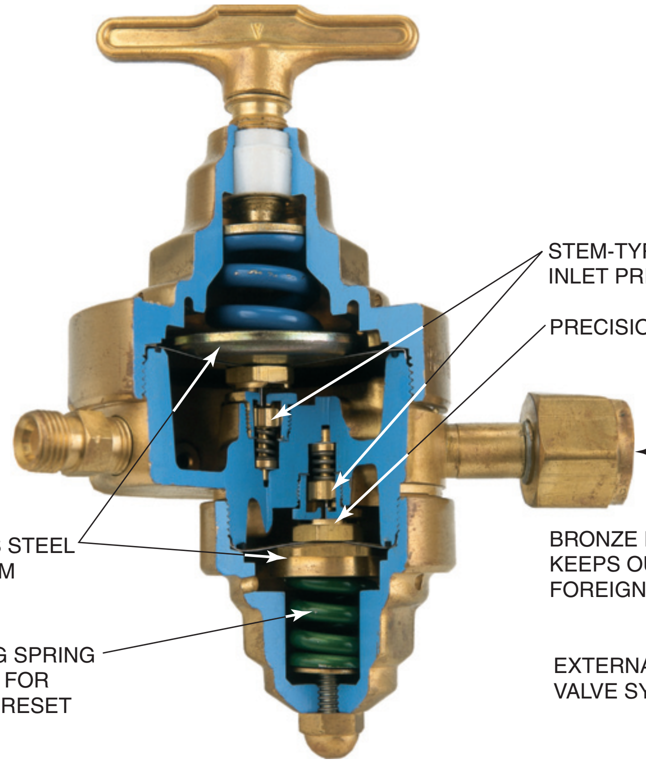


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FIGURE 7-20 Two-stage oxygen regulator.

cylinder empties. This type of regulator has two sets of springs, diaphragms, and valves. The first spring is preset at the factory to reduce the cylinder pressure to 225 psig (1550 kPag). The second spring is adjusted like other regulators. Because the second high-pressure valve has to control a maximum pressure of only approximately 225 psig (1550 kPag), it can be larger, thus allowing a greater flow.

REGULATOR GAUGES

There may be one or two pressure gauges on a regulator. One pressure gauge shows the working pressure, and the other indicates the cylinder pressure, **Figure 7-21**. The **working pressure** gauge shows the pressure at the regulator and not at the torch. The pressure at the torch is always less than the pressure shown on the working pressure gauge. This pressure difference results from the resistance to the gas flow, which is referred to as **line pressure drop**. The smaller in diameter or longer a line is, the greater the pressure drop will be, **Table 7-6**.

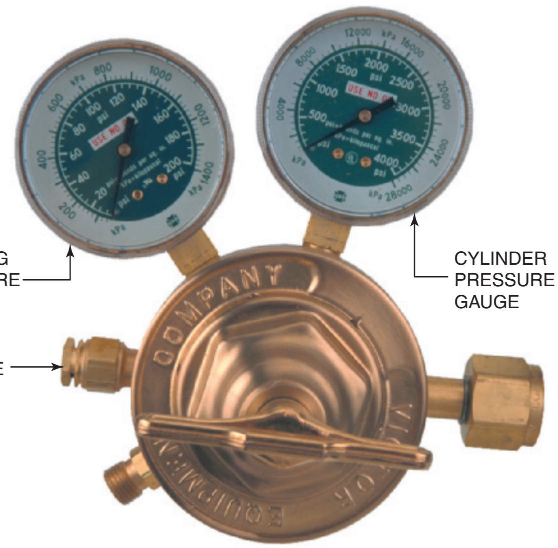

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FIGURE 7-21 Safety release valve on an oxygen regulator.

REGULATOR SAFETY PRESSURE RELEASE DEVICE

Regulators may be equipped with either a **safety release valve** or a **safety disc** to prevent excessively high pressures from damaging the regulator. A safety release valve is made up of a small ball held tightly against a **seat** by a spring. The release valve will reseat itself after the excessive pressure has been released.

A safety disc is a thin piece of metal held between two seals, **Figure 7-22**. When a safety disc bursts to release excessive pressure, all of the gas in the cylinder will be released. A safety disc does not reseal, so it must be replaced before the regulator can be used again.

CYLINDER AND REGULATOR FITTINGS

A variety of inlet or cylinder fittings are available to ensure that the regulator cannot be connected to the wrong gas or pressure, **Figure 7-23A** through **D**. A few adapters

Tip Pressure psig (kg/cm² G)	Regulator Pressure* for Hose Lengths ft (m)				
	10 ft (3 m)	25 ft (7.6 m)	50 ft (15.2 m)	75 ft (22.9 m)	100 ft (30.5 m)
1 (0.1)	1 (0.1)	2.25 (0.15)	3.5 (0.27)	4.75 (0.35)	6 (0.4)
5 (0.35)	5 (0.35)	6.25 (0.4)	7.5 (0.52)	8.75 (0.6)	10 (0.7)
10 (0.7)	10 (0.7)	11.25 (0.75)	12.5 (0.85)	13.75 (0.95)	15 (1.0)

*These values are for hose with a diameter of 1/4 in. (6 mm); larger or smaller hose diameters or high flow rates will change these pressures.

TABLE 7-6 Regulator Pressure for Various Lengths of Hose

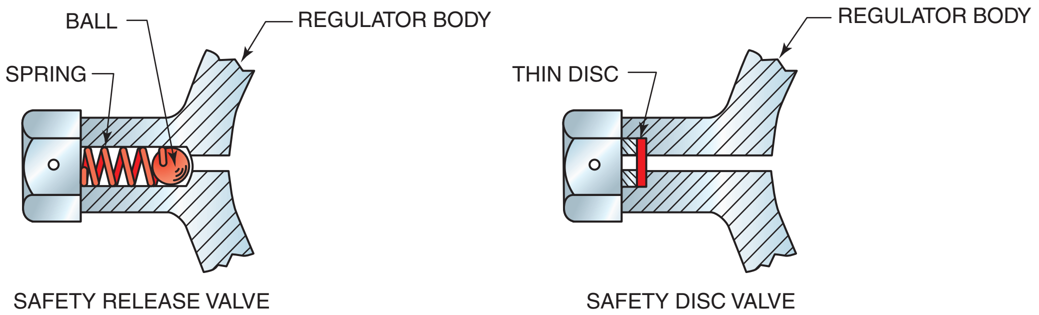

FIGURE 7-22 Pressure release valves.

FIGURE 7-23 Variety of inlet or cylinder fittings for the regulator. (A) Acetylene cylinder valve (left-hand thread). (B) Oxygen cylinder valve. (C) Argon cylinder valve. (D) Carbon dioxide (CO_2) cylinder valve.

(A)

(B)

FIGURE 7-24 (A) Acetylene cylinder adapter. (B) Carbon dioxide-to-argon adapter.

are available that will allow some regulators to be attached to a different type of fitting. The following are the two most common types: (1) adapt a left-hand male acetylene cylinder fitting to a right-hand female regulator fitting, or vice versa and (2) adapt an argon or mixed gas male fitting to a female flat washer-type CO_2 fitting, **Figure 7-24**.

The connections to the cylinder and to the hose must be kept free of dirt and oil. Fittings should screw together freely by hand and require only light wrench pressure to be leak tight. If the fitting does not tighten freely on the connection, then both parts should be cleaned. If the joint leaks after it has been tightened with a wrench, then the seat should be checked. Examine the seat and threads for damage. If the seat is damaged, it can be repaired by a manufacturer-authorized regulator repair shop. Severely damaged connections must be replaced.

REGULATOR SAFETY PRECAUTIONS

The regulator pressure adjusting screw should be backed off each time the oxyfuel system is being shut down. This is done to release the spring and diaphragm pressures, which, over time, may cause damage. Keeping a spring compressed and the diaphragm stretched can cause the spring to weaken and the diaphragm to be permanently distorted.

In addition, when the cylinder valve is reopened, some high-pressure gas can pass by the open high-pressure valve before the diaphragm can close it. This condition may cause the diaphragm to rupture or the low-pressure gauge to explode, or both.

High-pressure valve seats that leak result in **creep**, or rising pressure, on the working side of the regulator. This usually occurs when the gas pressure is set but no gas is flowing. If the leakage at the seat is severe, then the maximum safe pressure can be exceeded on the working side, resulting in damage to the diaphragm, gauge, hoses, or other equipment.

CAUTION

Regulators that creep excessively or beyond the safe working pressure must not be used.

A diaphragm can be tested for leaks by first setting the regulator to 14 psig (95 kPag) for fuel gases or 45 psig (310 kPag) for oxygen and other gases. Once the pressure is set, place a finger over the vent hole and spray it with a **leak-detecting solution**, **Figure 7-25**. Slowly move the finger from the hole and watch for bubbles, which indicate a leak.

A gauge that gives a faulty reading or that is damaged can result in dangerous pressure settings. Gauges that do not read “0” (zero) pressure when the pressure is released, or those that have damaged glass or case, must be repaired or replaced.

CAUTION

All work on regulators must be done by properly trained repair technicians.

CAUTION

Regulators should be located far enough from the actual work so that flames or sparks cannot reach them.

The outlet connection on a regulator is either a right-hand fitting for oxygen or a left-hand fitting for fuel gases. A left-hand threaded fitting has a notched nut, **Figure 7-26.**

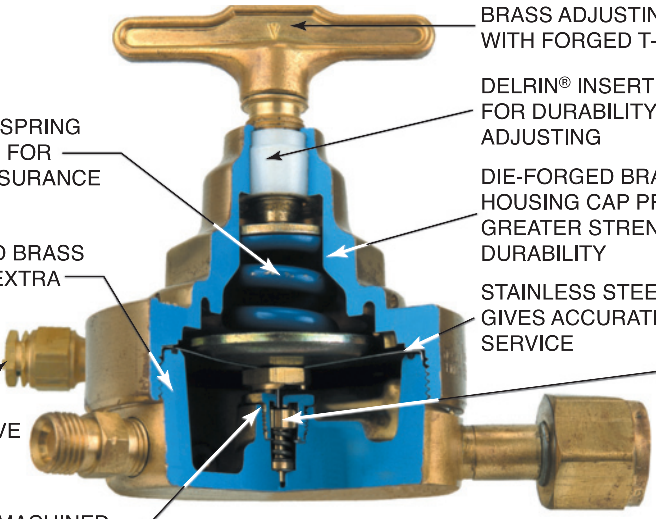

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FIGURE 7-25 Single-stage oxygen regulator.

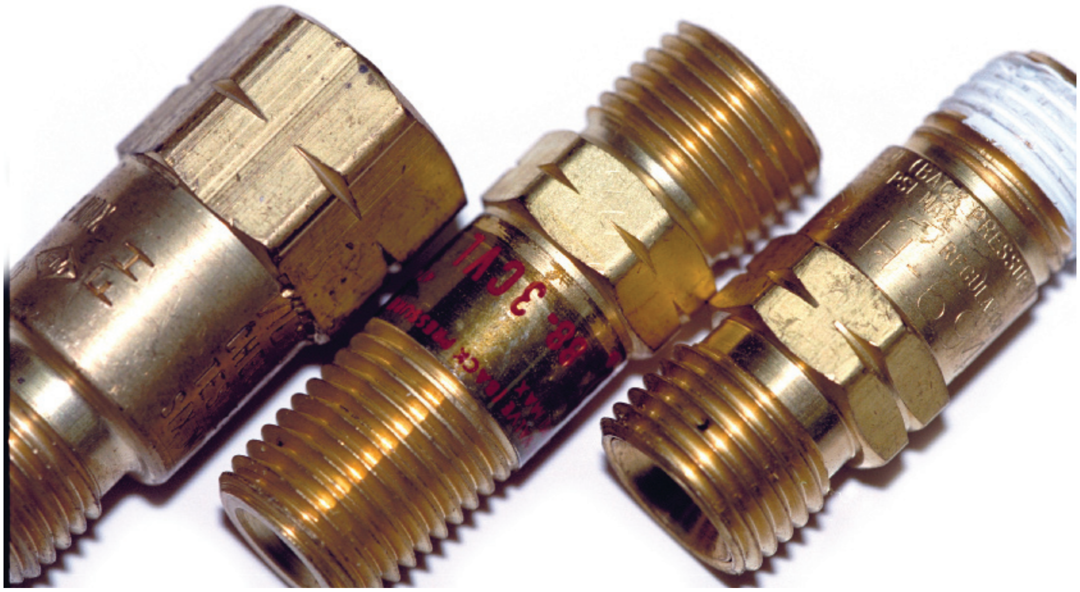

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FIGURE 7-26 Left-hand threaded fittings are identified with a notch.

REGULATOR CARE AND USE

There are no internal or external moving parts on a regulator or a gauge that require oiling, **Figure 7-27**.

CAUTION

Oiling a regulator is unsafe and may cause a fire or an explosion.

If the adjusting screw becomes tight and difficult to turn, it can be removed and cleaned with a dry, oil-free rag. When replacing the adjusting screw, be sure it does not become cross-threaded. Many regulators use a nylon nut in the regulator body, and the nylon is easily cross-threaded.

When welding is finished and the cylinders are turned off, the gas pressure must be released and the adjusting screw backed out. This is required both by federal regulation and to prevent damage to the diaphragm, gauges, and adjusting spring if they are left under a load. A regulator that is left pressurized causes the diaphragm to stretch, the Bourdon tube to straighten, and the adjusting spring to compress. These changes result in a less accurate regulator with a shorter life expectancy.

FIGURE 7-27 Never oil a regulator.

BACKFIRES

A backfire occurs when a flame goes out with a loud snap or pop. A backfire may be caused by one or more of the following:

- Touching the tip against the workpiece
- Overheating the tip
- Operating the torch when the flame settings are too low
- Loose tip
- Damaged seats
- Dirt in the tip

The problem that caused the backfire must be corrected before relighting the torch. A backfire may cause a flashback.

FLASHBACKS

When a flashback occurs, the flame is burning back inside the tip, torch, hose, or regulator. A flashback produces a high-pitched whistle. If the torch does flash back, close the oxygen valve at once and then close the fuel valve. The order in which the valves are closed is not as important as the speed at which they are closed. A flashback that reaches the cylinder may cause a fire or an explosion.

Closing the oxygen valve on the torch stops the flame inside immediately. Then, the fuel gas valve should be closed and the torch should be allowed to cool off before repairing the problem. When a flashback occurs, there is usually a serious problem with the equipment and a qualified technician should be called. After locating and repairing the problem, blow gas through the tip for a few seconds to clear out any soot that may have accumulated in the passages. A flashback that burns in the hose leaves a carbon char inside that may explode and burn in a pressurized oxygen system. A fuel gas is not required to kindle a hot, severe fire inside such hose sections. Discard hose sections in which a flashback has occurred and obtain new hose.

REVERSE FLOW AND FLASHBACK VALVES

The purpose of the reverse flow valve is to prevent gases from accidentally flowing through the torch and into the wrong hose. If the gases being used are allowed to mix in the hose or regulator, they might explode. The reverse flow valve is a spring-loaded check valve that closes when gas tries to flow backward through the torch valves, **Figure 7-28**. Some torches have reverse flow valves built into the torch body. Any torch that does not have them built in should have these safety devices added. If the torch does not come with a reverse flow valve, it must be added to either the torch end or regulator end of the hose.

A reverse flow of gas will occur if the torch is not turned off or bled properly. The torch valves must be opened one at a time so that the gas pressure in that hose will be vented into the atmosphere and not through the torch into the other hose, **Figure 7-29**.

CAUTION

If both valves are opened at the same time, one gas may be pushed back up the hose of the other gas.

A reverse flow valve will not stop the flame from a flashback from continuing through the hoses. A **flashback arrestor** will do the job of a reverse flow valve, and it will also stop the flame of a flashback, **Figure 7-30**. The flashback arrestor is designed to quickly stop the flow of gas during a flashback. These valves work on a similar principle as the gas valve at a service station. They are very sensitive to any back pressure in the hose and stop the flow if any back pressure is detected.

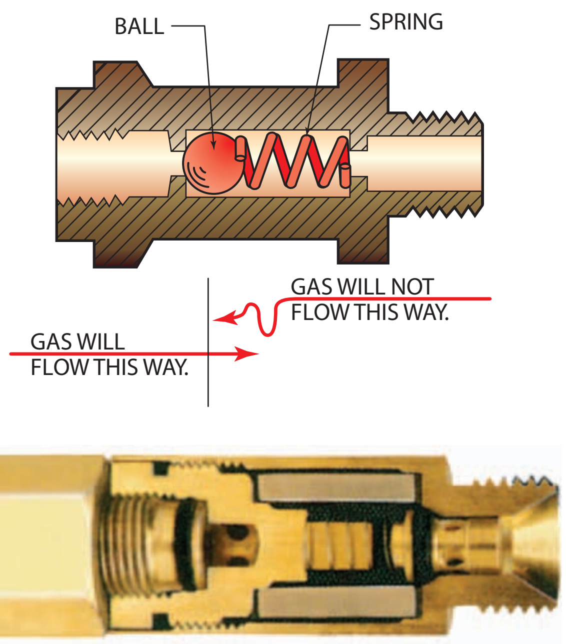

FIGURE 7-28 Reverse flow valve only.

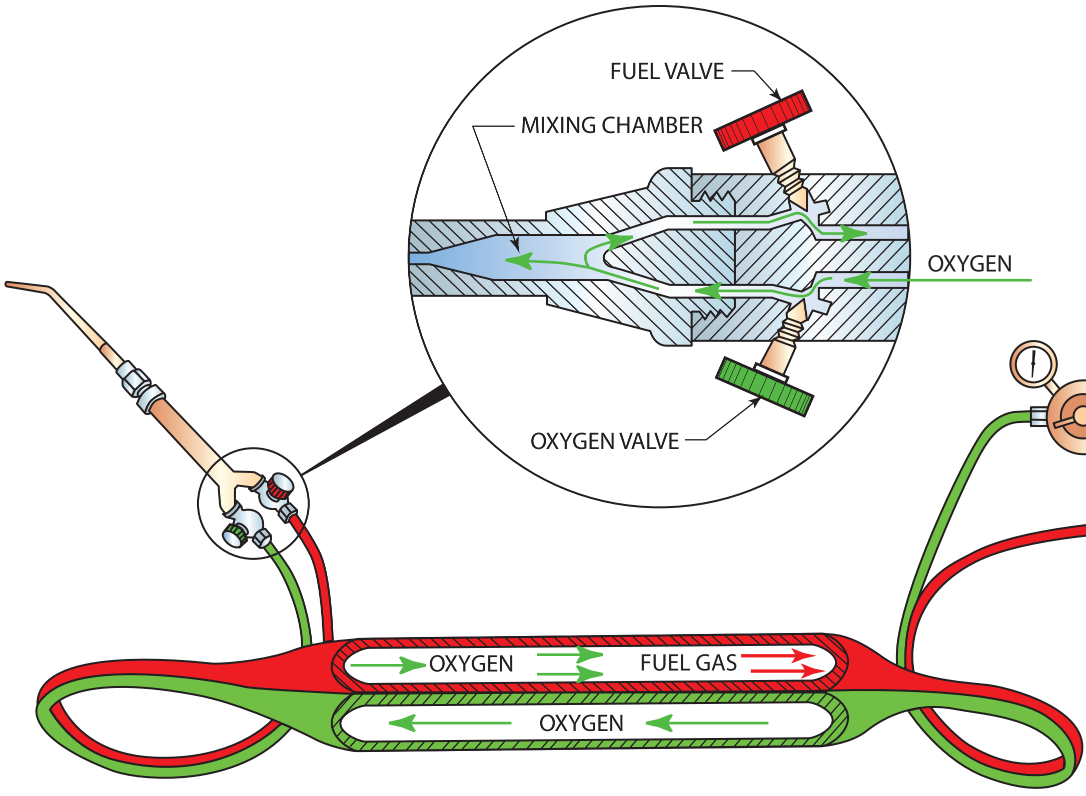

FIGURE 7-29 Gas may flow back up the hose if both valves are opened at the same time when the system is being bled down after use. Installing reverse flow valves on the torch can prevent this from occurring.

FIGURE 7-30 Combination flashback arrestors and check valves for (A) acetylene and (B) oxygen. (C) Replacement cartridge for flashback arrestor. (D) Torch designed with replaceable flashback arrestors and check valves built into the torch body.

CARE OF THE REVERSE FLOW VALVE AND FLASHBACK ARRESTOR

Both devices must be checked on a regular basis to see that they are working correctly. The internal valves may become plugged with dirt, or they may become sticky and not operate correctly. To test the reverse flow valve, you can try to blow air backward through the valve. To test the flashback arrestor, follow the manufacturer's recommended procedure. If the safety device does not function correctly, then it must be replaced.

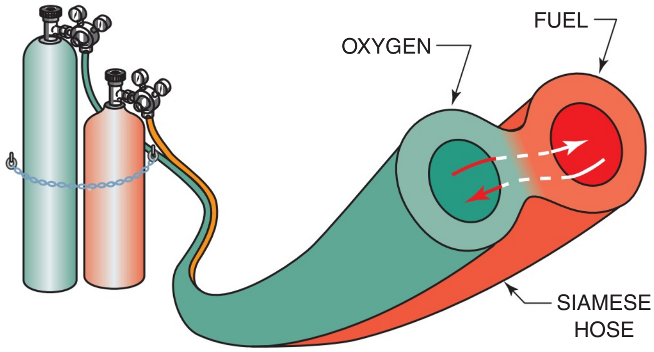

FIGURE 7-31 Gas left under pressure may migrate through the hose walls.

HOSES AND FITTINGS

Most welding hoses used today are molded together as one piece and are referred to as **Siamese hose**. Hoses that are not of the Siamese type, or hose ends that have separated, may be taped together. When taping the hoses, they must not be taped solidly. They should be wrapped approximately 2 in. (51 mm) out of every 12 in. (305 mm) of hose length, allowing the colors of the hose to be seen.

Fuel gas hoses must be red and have left-hand threaded fittings. Oxygen hoses must be green and have right-hand threaded fittings.

Hoses are available in four sizes: 3/16 in. (4.8 mm), 1/4 in. (6 mm), 5/16 in. (8 mm), and 3/8 in. (10 mm). The size given is the inside diameter of the hose. Larger sizes offer less resistance to gas flow and should be used when long hose lengths are required. The smaller sizes are more flexible and easier to handle for detailed work.

The three sizes of hose end fittings available are A (small), B (standard), and C (large). The three sizes are made to fit all hose sizes.

HOSE CARE AND USE

When hoses are not in use, the gas must be turned off and the pressure bled off. Turning off the equipment and releasing the pressure prevent any undetected leaks from causing a fire or an explosion. This action also eliminates a dangerous situation that would be created if a hose were cut by equipment or if materials were being handled by workers who were unfamiliar with welding equipment. In addition, hoses are permeable to gases (ability of the gas to pass into or through the hose walls). Thus, gases left under pressure for long periods of time can migrate through the hose walls and mix with each other, **Figure 7-31**. If the gases mix and the torch is lit without first purging the lines, the hoses can explode. For this reason, if the welder is not certain that the hoses were bled, it is recommended that they be purged before the torch is lit.

Hoses are resistant to burns, but they are not burnproof. They should be kept out of direct flame, sparks, and hot metal. You must be especially cautious when using a cutting torch. If it becomes damaged, the damaged section should be removed and the hose should be repaired with a splice. Damaged hoses should never be taped to stop leaks.

Hoses should be checked periodically for leaks. To test a hose for leaks, adjust the regulator to a working pressure with the torch valves closed. Wet the hose with a leak-detecting solution by rubbing it with a wet rag, spraying it, or dipping it in a bucket. Then, watch for bubbles, which indicate that the hose leaks.

The hose fittings can be changed if the old ones become damaged. Several kits are available that have new nuts, nipples, ferrules, a ferrule crimping tool, and any other supplies required to replace the hose ends, **Figure 7-32**.

To replace the hose end, the hose is first cut square. The correct size ferrule is inserted. Then, both the hose end and nipple are sprayed with a leak-detecting solution. This will help the nipple slide in more easily. Screw the nipple and nut on a torch body. This will hold the nipple deep inside the nut, and the body will act as a handle for leverage as the nipple is pushed inside the hose, **Figure 7-33**. After

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FIGURE 7-32 Hose repair kit.

FIGURE 7-33 Screwing the hose nut onto a fitting will help when pushing the nipple into the hose.

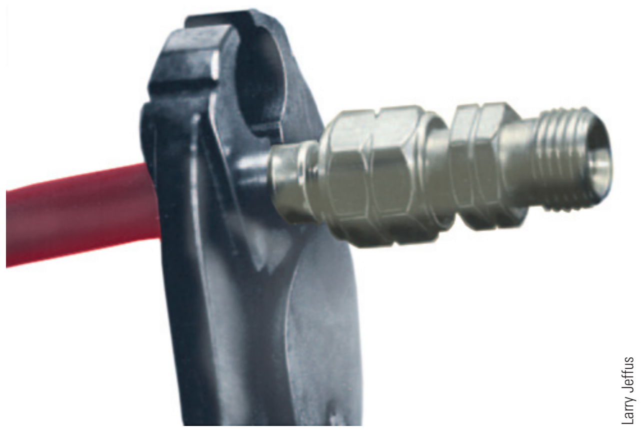

FIGURE 7-34 Crimping hose ferrule.

the hose is slid up to the nut, crimp the ferrule until it is tight. The crimping tool should be squeezed twice, with the second time at right angles to the first, **Figure 7-34**. When the crimping is complete, install the hose on a torch and regulator. Then, adjust the regulator to a working pressure and spray the fitting with a leak-detecting solution. Watch for any bubbles, which indicate a leaking fitting.

LEAK DETECTION

A leak-detecting solution can be purchased premixed and ready to use or as a concentrate that must be mixed with water.

A leak-detecting solution must be free-flowing so that it can seep into small joints, cracks, and other areas that may have a leak. The solution must produce a good quantity of bubbles without leaving a film. The solution can be dipped, sprayed, or brushed on the joints.

CAUTION

Some detergents are not suitable for O_2 because of an oil base. Use only O_2-approved leak-detection solutions on oxygen fittings.

OXYFUEL CUTTING, SETUP, AND OPERATION

The setting up of a cutting torch system is exactly like setting up oxyfuel welding equipment, except for the adjustment of gas pressures. This chapter covers gas pressure adjustments and cutting equipment operations.

TORCH TIP CARE AND USE

Torch tips may have metal-to-metal seals, or they may have an O-ring or a gasket between the tip and the torch seat. Metal-to-metal seal tips must be tightened with a wrench. Tips with an O-ring or a gasket may be tightened by hand. Using the wrong method of tightening the tip fitting may result in damage to the torch body or the tip.

Dirty tips can be cleaned using a set of tip cleaners. Using the file provided in the tip-cleaning set, **Figure 7-35**, file the end of the tip smooth and square. Next, select the size of tip cleaner that fits easily into the orifice. The tip cleaner is a small, round file and should be moved in and out of the orifice only a few times, **Figure 7-36**. Be sure the tip cleaner is straight and that it is held steady to prevent it from bending or breaking off in the tip. Excessive use of the tip cleaner tends to ream the orifice, making it too large. Therefore, use the tip cleaner only as required. Once the tip is cleaned, turn on the oxygen for a moment to blow out any material loosened during the cleaning.

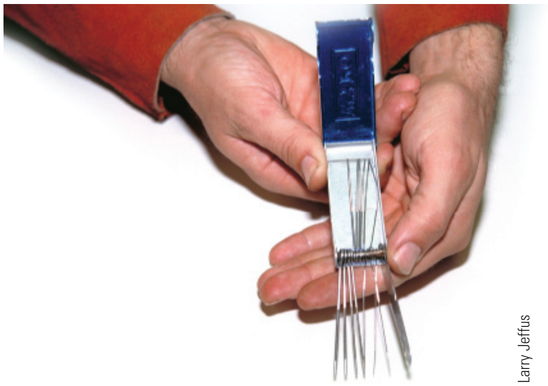

FIGURE 7-35 Standard set of tip cleaners.

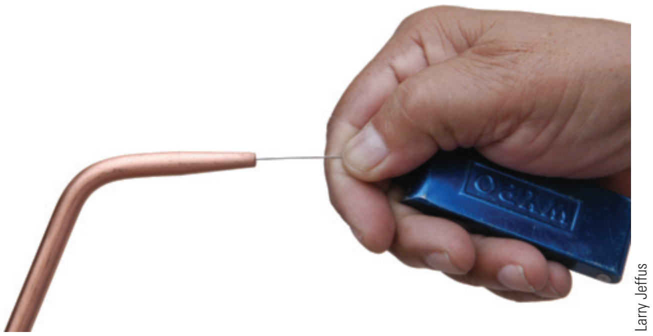

FIGURE 7-36 Cleaning a tip with a standard tip cleaner.

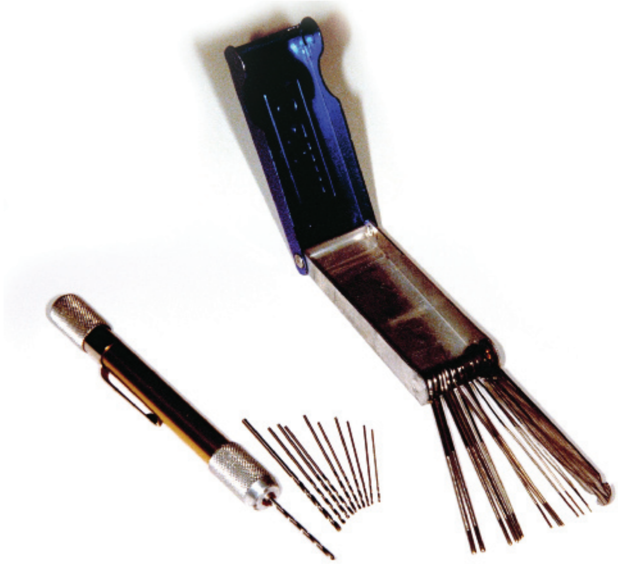

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FIGURE 7-37 Tools used to repair tips.

Damaged tips or tips with cleaners broken in them can be reconditioned, but they require a good deal of work and some specialized tools, **Figure 7-37**.

PRACTICE 7-1

Setting Up a Cutting Torch

Demonstrate to other students and your instructor the proper method of setting up cylinders, regulators, hoses, and the cutting torch.

1. The oxygen and acetylene cylinders must be securely chained to a cart or wall before the safety caps are removed.
2. After removing the safety caps, stand to one side and crack (open and quickly close) the cylinder valves, being sure there are no sources of possible ignition that may start a fire. Cracking the cylinder valves is done to blow out any dirt that may be in the valves.
3. Visually inspect all of the parts for any damage, needed repair, or cleaning.
4. Attach the regulators to the cylinder valves and tighten them securely with a wrench.
5. Attach a reverse flow valve or flashback arrestor, if the torch does not have them built in, to the hose connection on the regulator or to the hose connection on the torch body, depending on the type of reverse flow valve in the set. Occasionally, test each reverse flow valve by blowing through it to make sure it works properly.
6. If the torch you will be using is a combination-type torch, attach the cutting head at this time.
7. Finally, install a cutting tip on the torch.
8. Before the cylinder valves are opened, back out the pressure regulating screws so that when the valves are opened the gauges will show zero pounds of working pressure.
9. Stand to one side of the regulator's face as the cylinder valves are opened slowly.
10. The oxygen valve is opened all the way until it becomes tight, but do not overtighten, and the acetylene valve is opened no more than one-half turn.
11. Open one torch valve and then turn the regulating screw in slowly until 2 psig to 4 psig (14 kPag to 30 kPag) shows on the working pressure gauge. Allow the gas to escape so that the line is completely purged.
12. If you are using a combination welding and cutting torch, the oxygen valve nearest the hose connection must be opened before the flame adjusting valve or cutting lever will work.
13. Close the torch valve and repeat the purging process with the other gas.
14. Be sure there are no sources of possible ignition that may result in a fire.
15. With both torch valves closed, spray a leak-detecting solution on all connections, including the cylinder valves. Tighten any connection that shows bubbles, **Figure 7-38**.

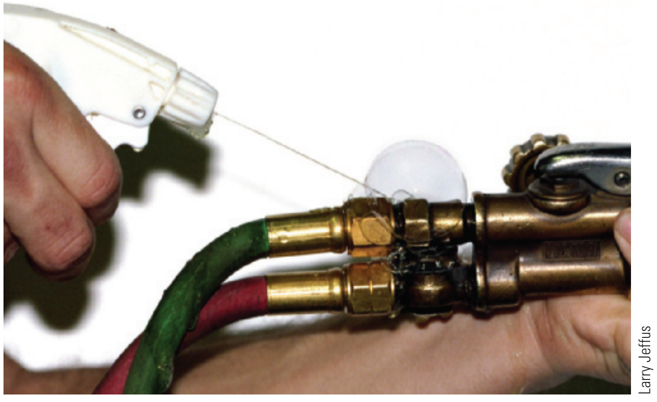

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FIGURE 7-38 Leak-check all gas fittings.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 7-2

Cleaning a Cutting Tip

Using a cutting torch set that is assembled and adjusted as described in Practice 7-1 and a set of tip cleaners, you will clean the cutting tip.

1. Turn on a small amount of oxygen, **Figure 7-39**. This procedure is done to blow out any dirt loosened during the cleaning.
2. The end of the tip is first filed flat, using the file provided in the tip cleaning set, **Figure 7-40**.

FIGURE 7-39 Turn on the oxygen valve.

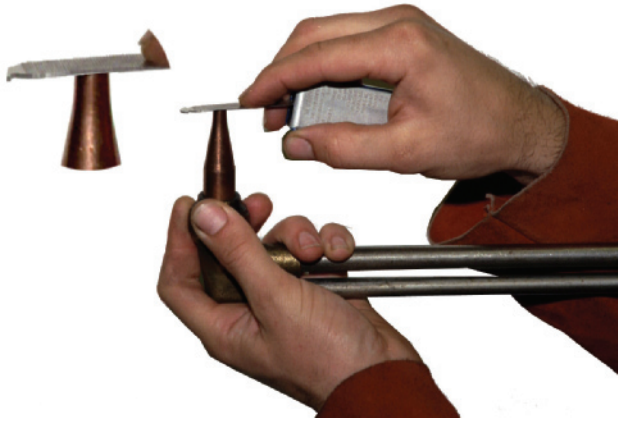


FIGURE 7-40 File the end of the tip flat.

3. Try several sizes of tip cleaners in a preheat hole until the correct size cleaner is determined. It should easily go all the way into the tip, **Figure 7-41**.
4. Push the cleaner in and out of each preheat hole several times. Tip cleaners are small, round files. Excessive use of them will greatly increase the **orifice** (hole) size.
5. Next, depress the cutting lever and, by trial and error, select the correct size tip cleaner for the center cutting orifice.

FIGURE 7-41 A tip cleaner should be used to clean the flame and center cutting holes.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 7-3

Lighting the Torch

Wearing welding goggles, gloves, and any other required personal protective clothing, and with a cutting torch set that is safely assembled, you will light the torch.

1. Set the regulator working pressure for the tip size. If you do not know the correct pressure for the tip, start with the fuel set at 5 psig (35 kPag) and the oxygen set at 25 psig (170 kPag).
2. Point the torch tip upward and away from any equipment or other students.
3. Turn on just the acetylene valve and only use a spark lighter to ignite the acetylene. If the acetylene flow is too high, the torch may not stay lit. If this happens, close the valve slightly and try to relight the torch.
4. If the flame is small, it will produce heavy black soot and smoke. In this case, turn the flame up to stop the soot and smoke. The welder does not need to be concerned if the flame jumps slightly away from the torch tip.
5. With the acetylene flame burning smoke-free, slowly open the oxygen valve, and by using only the oxygen valve adjust the flame to a neutral setting, **Figure 7-42**.
6. When the cutting oxygen lever is depressed, the flame may become slightly carbonizing. This may occur because of a drop in line pressure due to the high flow of oxygen through the cutting orifice.
7. With the cutting lever depressed, readjust the preheat flame to a neutral setting. The flame will become slightly oxidizing when the cutting lever is released. Since an oxidizing flame is hotter than a neutral flame, the metal being cut will be preheated faster. When the cut is started by depressing the lever, the flame automatically returns to the neutral setting and does not oxidize the top of the plate.
8. Extinguish the flame by first turning off the oxygen and then the acetylene.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

CAUTION

Turning off the acetylene first will often cause a loud popping sound. This can often cause soot to clog the tip and torch.

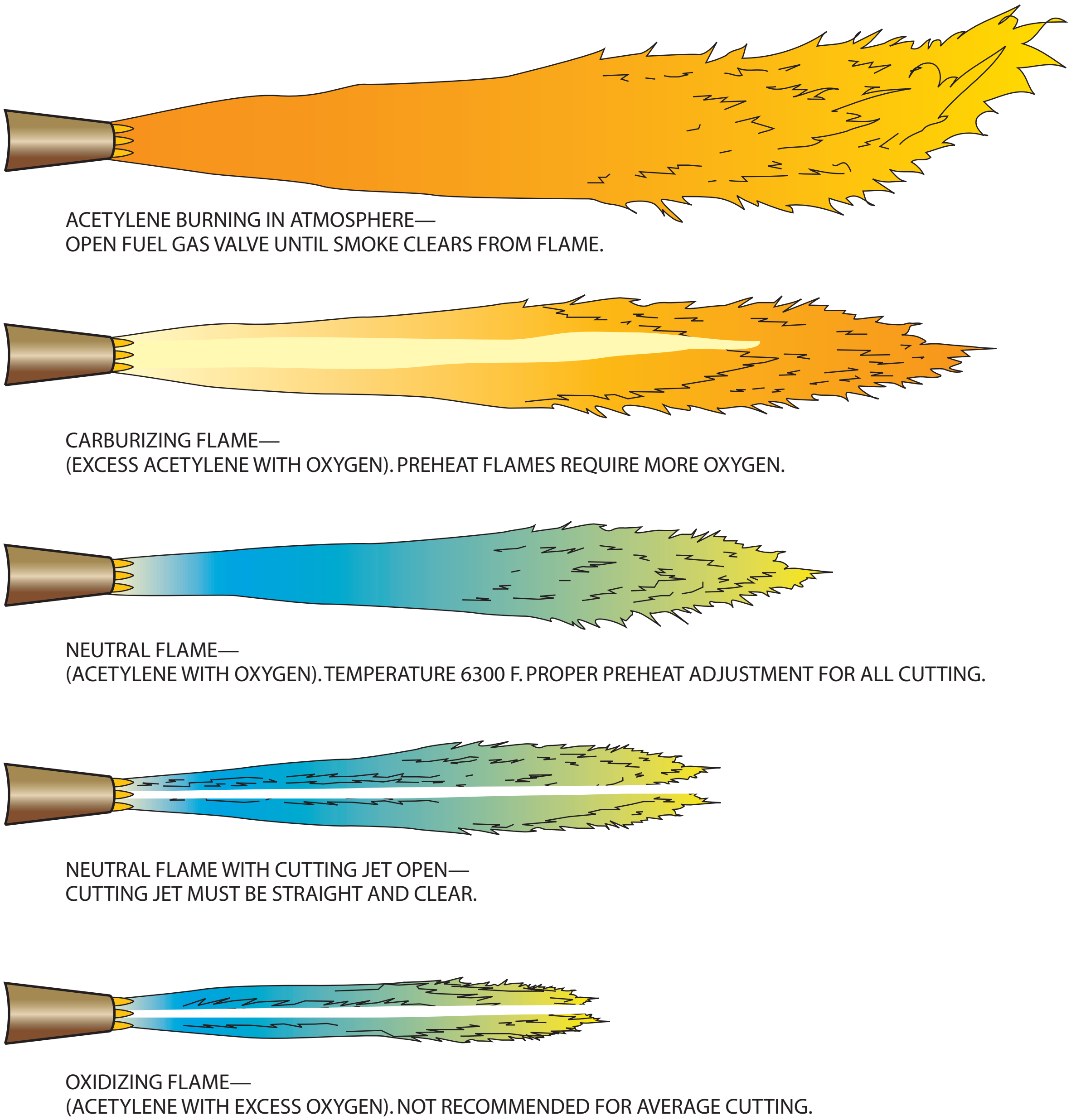


FIGURE 7-42 Oxyacetylene flame adjustments for the cutting torch.

HAND CUTTING

When making a cut with a hand torch, it is important for the welder to be steady to make the cut as smooth as possible. A welder must also be comfortable and free to move the torch along the line to be cut. It is a good idea for a welder to get into position and practice the cutting movement a few times before lighting the torch. Even when the welder and the torch are braced properly, a tiny movement such as a heartbeat will cause a slight ripple in the cut. Attempting a cut without leaning on the work, to brace oneself, is tiring and causes inaccuracies.

The torch should be braced with the left hand if the welder is right-handed or with the right hand if the welder is left-handed. The torch may be moved by sliding it toward you over your supporting hand, **Figure 7-43**

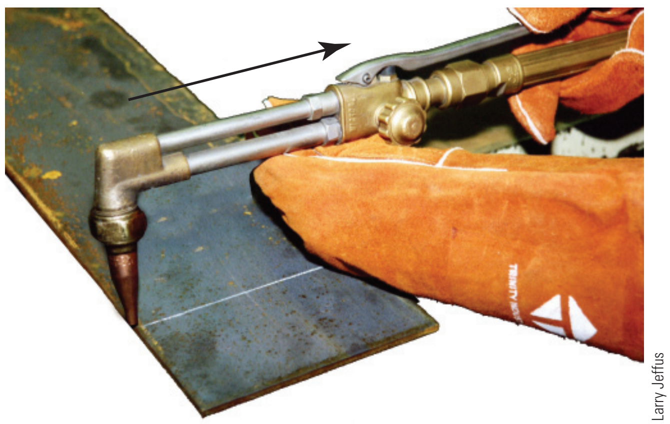
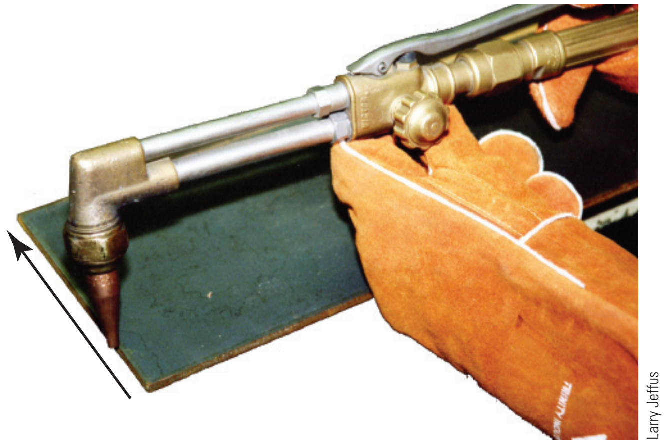
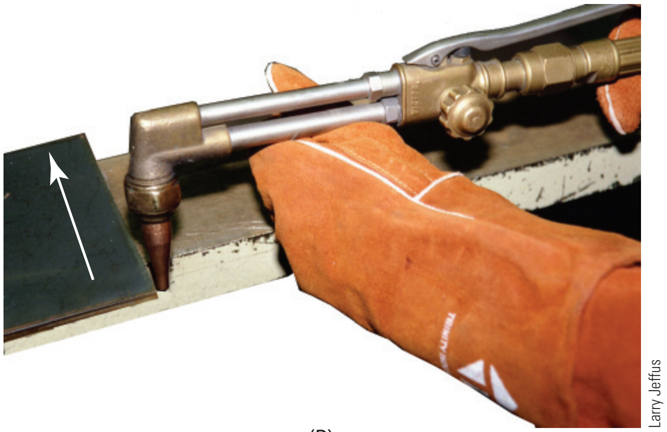


FIGURE 7-43 For short cuts, the torch can be drawn over the gloved hand.



(A)



(B)

FIGURE 7-44 For longer cuts, the torch can be moved by sliding your gloved hand along the plate parallel to the cut: (A) start and (B) finish. Always check for free and easy movement before lighting the torch.

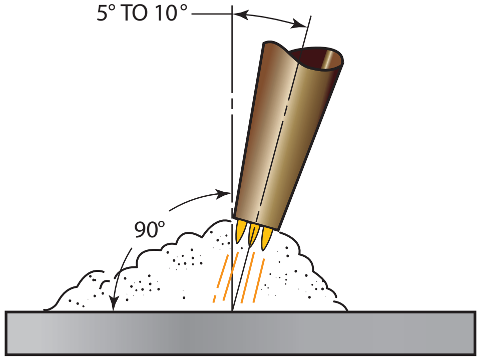


FIGURE 7-45 A slight forward angle helps when cutting thin material.

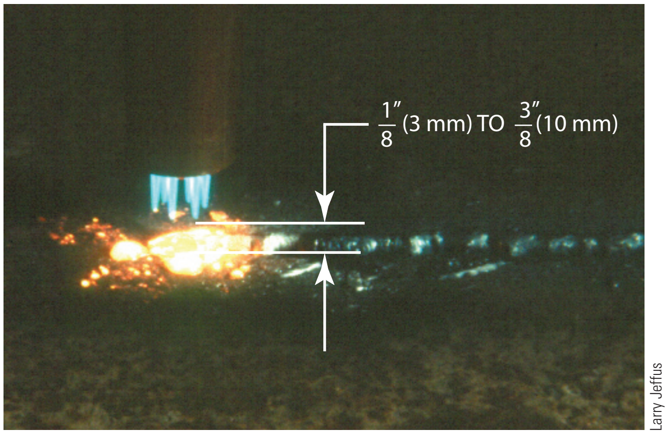


FIGURE 7-46 Inner cone to work distance.

and **Figure 7-44**. The torch can also be pivoted on the supporting hand. If the pivoting method is used, care must be taken to prevent the cut from becoming a series of arcs.

A slight forward torch angle helps the flame preheat the metal, keeps some of the reflected flame heat off the tip, aids in blowing dirt and oxides away from the cut, and keeps the tip clean for a longer period of time because slag is less likely to be blown back on it, **Figure 7-45**. The forward angle can be used only for a straight line square cut. If shapes are cut using a slight angle, the part will have beveled sides.

When making a cut, the inner cones of the flame should be kept 1/8 in. (3 mm) to 3/8 in. (10 mm) from the surface of the plate, **Figure 7-46**. This distance is known as the **coupling distance**.

To start a cut on the edge of a plate, hold the torch at a right angle to the surface or pointed slightly away from the edge, **Figure 7-47**. The torch must also be pointed so that the cut is started at the very edge. The edge of the plate heats up more quickly and allows the cut to be started

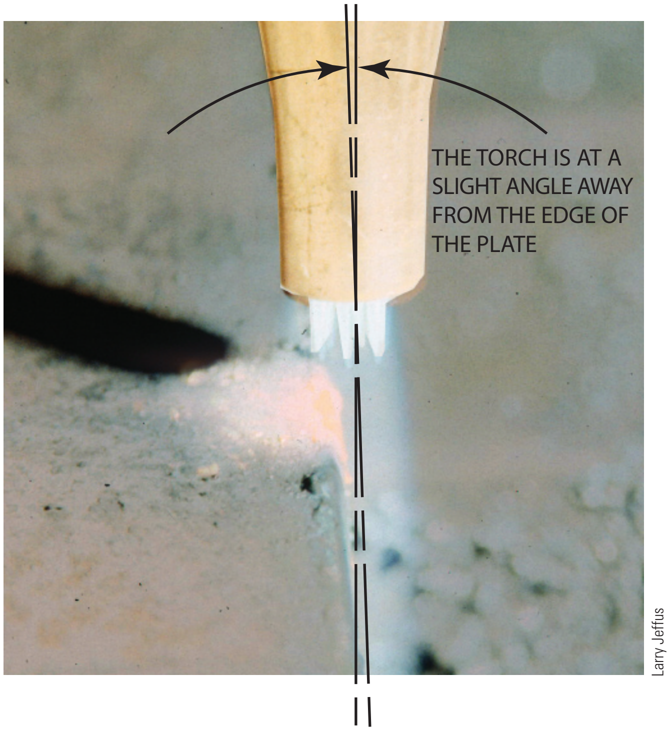


FIGURE 7-47 Starting a cut on the edge of a plate. Notice how the torch is pointed at a slight angle away from the edge.

sooner. Also, fewer sparks will be blown around the shop. Once the cut is started, the torch should be rotated back to a right angle to the surface or to a slight leading angle.

CAUTION

NEVER USE A CUTTING TORCH TO CUT OPEN A USED CAN, DRUM, TANK, OR OTHER SEALED CONTAINERS. The heat, sparks, and oxygen cutting stream may cause even nonflammable residue inside to burn or explode. Dangerous vapors and fumes may also be released during the cutting process if the container is not properly cleaned.

If a cut is to be started in a place other than the edge of the plate, the inner cones should be held as close as possible to the metal. Having the inner cones touch the metal will speed up the preheat time. When the metal is hot enough to allow the cut to start, the torch should be raised as the cutting lever is slowly depressed. When the metal is pierced, the torch should be lowered again, **Figure 7-48**. By raising the torch tip away from the metal, the amount of sparks blown into the air is reduced and the tip is kept cleaner. If the metal being cut is thick, it may be necessary to move the torch tip in a small circle as the hole pierces the metal. If the metal is to be cut in both directions from the spot where it was pierced, the torch should be moved backward a short distance and then forward, **Figure 7-49**. This prevents slag from refilling the kerf at the starting

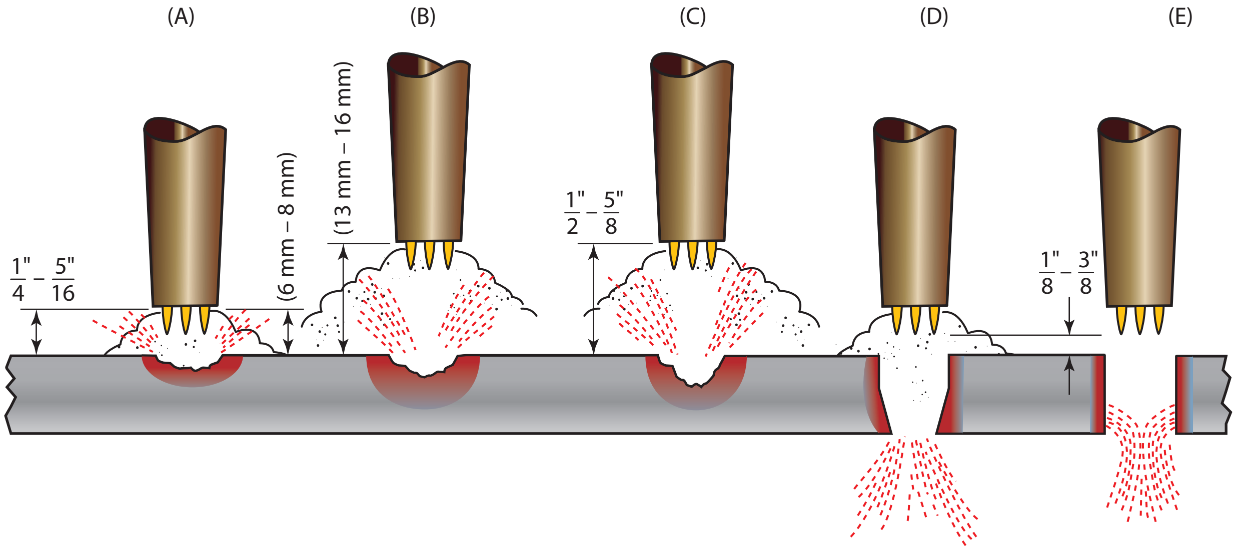


FIGURE 7-48 When piercing a plate to start a cut, hold the torch tip close to the surface of the plate (A). When the metal is hot enough, slowly depress the cutting lever and raise the torch to avoid blowing slag back onto the tip (B and C). When the plate has been pierced completely, lower the torch (D). Begin moving the torch along the line to be cut (E).

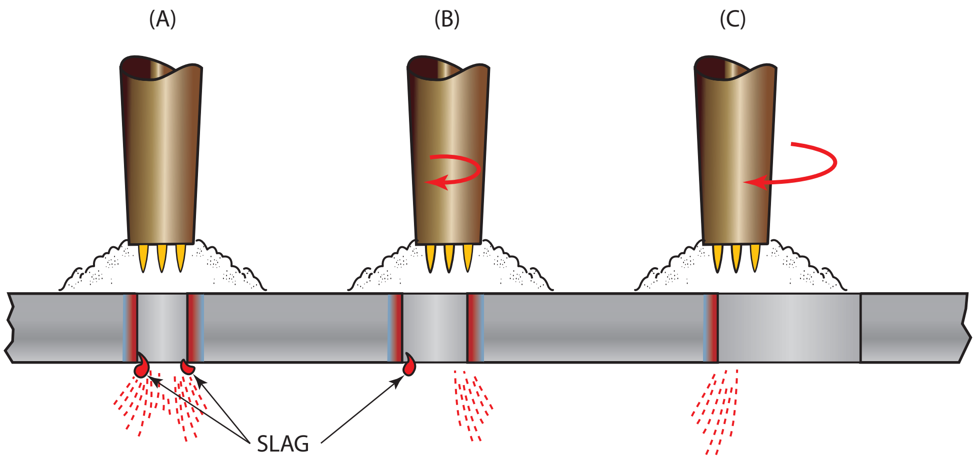


FIGURE 7-49 (A) A short, backward movement (B) before the cut is carried forward (C) clears the slag from the kerf. Slag left in the kerf may cause the cutting stream to gouge into the base metal, resulting in a poor cut.

point, thus making it difficult to cut in the other direction. The kerf is the space produced during any cutting process.

THINK GREEN

Avoid Contaminating the Environment

Any residue of the chemicals that remain in a container must be cleaned out properly before cutting can begin. Refer to the material's manufacturer and material safety data sheet (MSDS) to determine how to safely clean out the container. Any spilled material must be cleaned promptly so it will not be washed away by rainwater where it could contaminate the environment.

In addition to the possible direct soil and water contamination that could be caused by the chemicals, the heat of the cutting torch can release air pollutants.

Starts and stops can be made more easily and better when one side of the metal being cut is scrap, because the torch can be turned out a short distance onto the scrap side of the cut before the cut is stopped, **Figure 7-50**. The extra space that this procedure provides will allow a smoother and more even start with less chance that slag will block the cut. If neither side of the cut is to be scrap, then the forward movement should be stopped for a moment before releasing the cutting lever. This action will allow the **drag**, or the distance that the bottom of the cut is behind the top, to catch up before stopping, **Figure 7-51**. To restart, use the same procedure that was given for starting a cut at the edge of the plate.

The proper alignment of the preheat holes will speed up and improve the cut. The holes should be aligned so that one is directly on the line ahead of the cut and another is aimed down into the cut when making a straight line square cut, **Figure 7-52**. The flame is directed toward the smaller piece and the sharpest edge when cutting a bevel. For this reason, the tip should be changed so that at least two of the flames are on the larger plate and none of the flames is directed on the sharp edge, **Figure 7-53**. If the preheat flame is directed at the edge, it will be rounded as it is melted back.

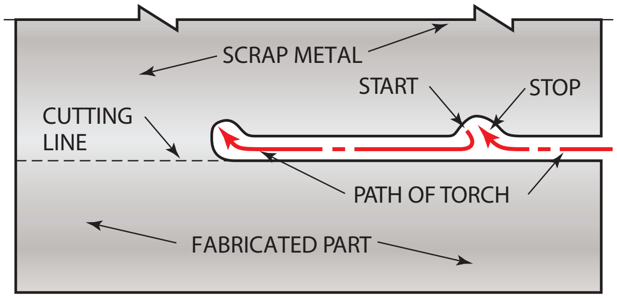


FIGURE 7-50 Turning out into scrap to make stopping and starting points smoother.

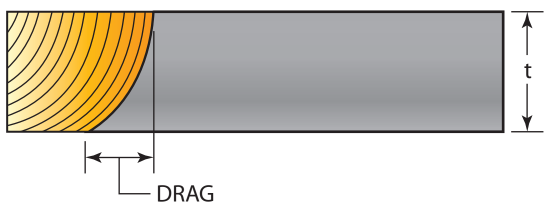


FIGURE 7-51 Drag is the distance by which the bottom of a cut lags behind the top.

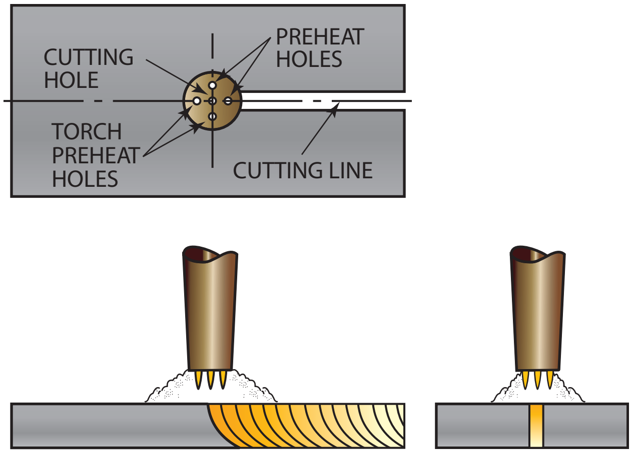


FIGURE 7-52 Tip alignment for a square cut.

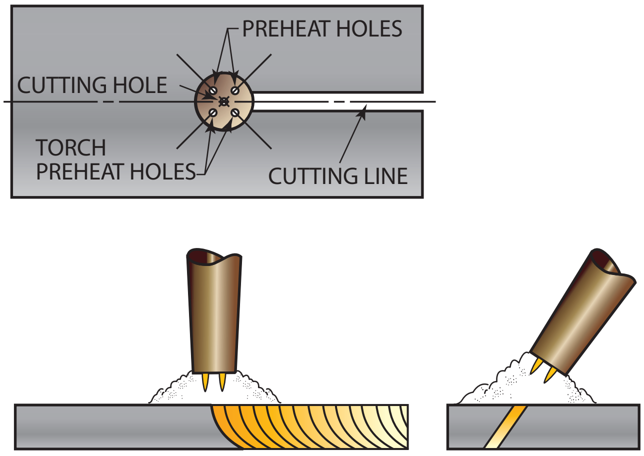


FIGURE 7-53 Tip alignment for a bevel cut.

LAYOUT

Laying out a line to be cut can be done with a piece of **soapstone** or a chalk line. To obtain an accurate line, a scribe or a punch can be used. If a piece of soapstone is used, it should be sharpened properly to increase accuracy, **Figure 7-54**. A chalk line will make a long, straight line on metal and is best used on large jobs. The scribe and punch can both be used to lay out an accurate line, but the punched line is easier to see when cutting. A punch can be held as shown in **Figure 7-55**, with the tip just above the surface of the metal. When the punch is struck with a lightweight hammer, it will make a mark. If you move your

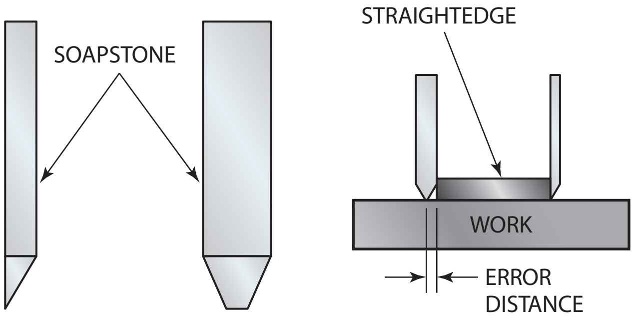


FIGURE 7-54 Proper method of sharpening a soapstone.

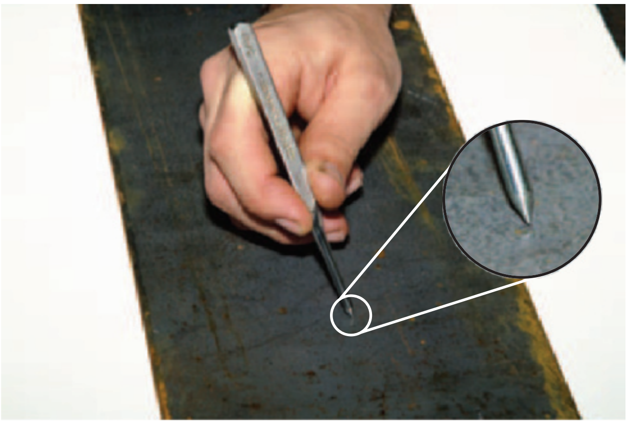


FIGURE 7-55 Holding the punch slightly above the surface allows the punch to be struck rapidly and moved along a line to mark it for cutting.

hand along the line and rapidly strike the punch, it will leave a series of punch marks for the cut to follow.

SELECTING THE CORRECT TIP AND SETTING THE PRESSURE

Each welding equipment manufacturer uses its own numbering system to designate the tip size. It would be impossible to remember each of the systems. Each manufacturer, however, does relate the tip number to the numbered drill size used to make the holes. On the back of most tip cleaning sets, the manufacturer lists the equivalent drill size of each tip cleaner. By remembering approximately which tip cleaner was used on a particular tip for a metal thickness range, a welder can easily select the correct tip when using a new torch set. Using the tip cleaner that you are familiar with, try it in the various torch tips until you find the correct tip that the tip cleaner fits. **Table 7-7** lists the tip drill size, pressure range, and metal thickness range for which the tip can be used.

Metal Thickness in. (mm)	Center Orifice Size		Oxygen Pressure lb/in.^{2} (kPa)	Acetylene lb/in.^{2} (kPa)
	No. Drill	Tip Cleaner No.*		
1/8 (3)	60	7	10 (70)	3 (20)
1/4 (6)	60	7	15 (100)	3 (20)
3/8 (10)	55	11	20 (140)	3 (20)
1/2 (13)	55	11	25 (170)	4 (30)
3/4 (19)	55	11	30 (200)	4 (30)
1 (25)	53	12	35 (240)	4 (30)
2 (51)	49	13	45 (310)	5 (35)
3 (76)	49	13	50 (340)	5 (35)
4 (102)	49	13	55 (380)	5 (35)
5 (127)	45	**	60 (410)	5 (35)

*The tip cleaner number when counted from the small end toward the large end in a standard tip cleaner set.

**This orifice size is larger than any tip cleaner in a standard set.

TABLE 7-7 Cutting Pressure and Tip Size

PRACTICE 7-4

Setting the Gas Pressures

Setting the working pressure of the regulators can be done by following a table, or it can be set by watching the flame. Following all the equipment manufacturer's operation and safety instructions, and using all required personal protective equipment, you are going to light and adjust the oxyacetylene flame.

1. To set the regulator by watching the flame, first set the acetylene pressure at 2 psig to 4 psig (14 kPag to 30 kPag) and then light the acetylene flame.
2. Open the acetylene torch valve one to two turns and reduce the regulator pressure by backing out the setscrew until the flame starts to smoke.
3. Increase the pressure until the smoke stops, and then increase it just a little more. This is the maximum fuel gas pressure the tip needs. With a larger tip and a longer hose, the pressure must be set higher. This is the best setting, and it is the safest one to use. With this lowest possible setting, there is less chance of a leak. If the hoses are damaged, the resulting fire will be much smaller than a fire burning from a hose with a higher pressure. There is also less chance of a leak with the lower pressure.
4. With the acetylene adjusted so that the flame just stops smoking, slowly open the torch oxygen valve.
5. Adjust the torch to a neutral flame. When the cutting lever is depressed, the flame will become carbonizing, not having enough oxygen pressure.
6. While holding the cutting lever down, increase the oxygen regulator pressure slightly. Readjust the flame, as needed, to a neutral setting by using the oxygen valve on the torch.
7. Increase the pressure slowly and readjust the flame as you watch the length of the clear cutting stream

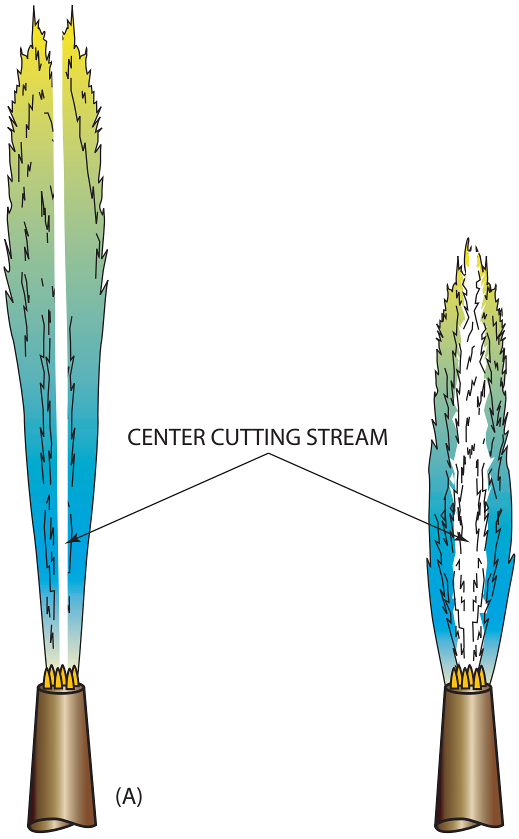


FIGURE 7-56 A clean cutting tip will have a long well-defined oxygen stream (A) as compared to a shorter more turbulent one with a dirty tip (B).

in the center of the flame, **Figure 7-56A**. The center stream will stay fairly long until a pressure is reached that causes turbulence, disrupting the cutting stream. This turbulence will cause the flame to shorten in length considerably, **Figure 7-56B**.

8. With the cutting lever still depressed, reduce the oxygen pressure until the flame lengthens once again. This is the maximum oxygen pressure that this tip can use without disrupting turbulence in the cutting stream. This turbulence will cause a very poor cut. The lower pressure also will keep the sparks from being blown a longer distance from the work, **Figure 7-57**.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

THINK GREEN

To Avoid Contaminating the Environment

Properly dispose of oils, paints, and other hazardous materials cleaned from metal parts that are going to be cut so they do not contaminate the environment.

CAUTION

Some metals release harmful oxides when they are cut. Extreme caution must be taken when cutting used, oily, dirty, or painted metals. They often produce very dangerous fumes when they are cut. You may need extra ventilation and a respirator to be safe. Check with the welding shop foreman or shop safety officer before cutting any metal you are unfamiliar with.

The center piece of a hole being cut will quickly become red hot and will start to oxidize with the surrounding air as a result of the iron burning in the cutting stream, **Figure 7-58**. With some cuts, the heat produced may overheat small strips of metal being cut from a larger piece. Also, the heat can make it difficult to cut out small or internal parts.

EXPERIMENT 7-1

Observing Heat Produced during a Cut

This experiment may require more skill than you have developed by this time. You may wish to observe your instructor performing the experiment or try it at a later time.

Using a properly lit and adjusted cutting torch, welding gloves, appropriate eye protection, protective clothing, all other required personal protective equipment, and one

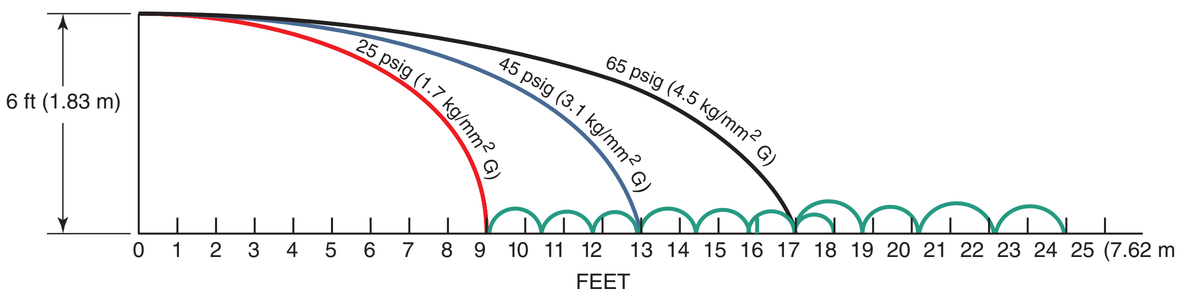
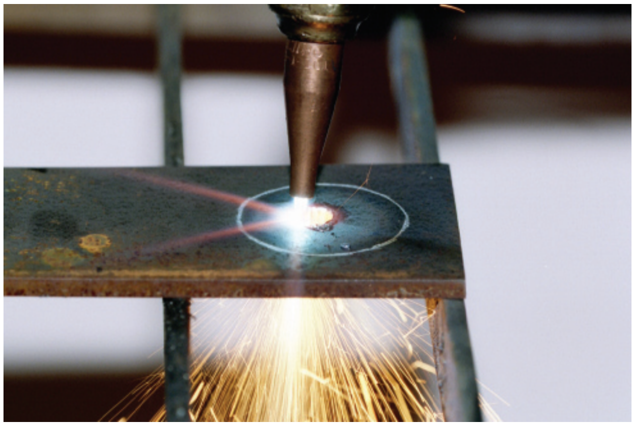
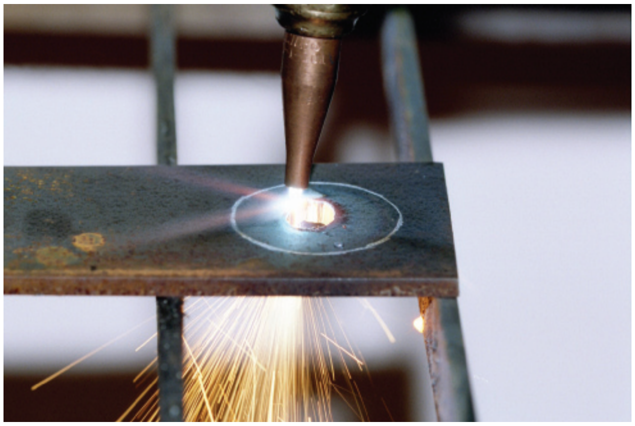


FIGURE 7-57 The sparks from cutting a mild steel plate, 3/8 in. (10 mm) thick, 6 ft (1.8 m) from the floor, will be thrown much farther if the cutting pressure is too high for the plate thickness. These cuts were made with a Victor cutting tip no. 0-1-101 using 25 psig (1.7 kg/mm^2) as recommended by the manufacturer, and by excessive pressures of 45 psig (3.1 kg/mm^2) and 65 psig (4.5 kg/mm^2).



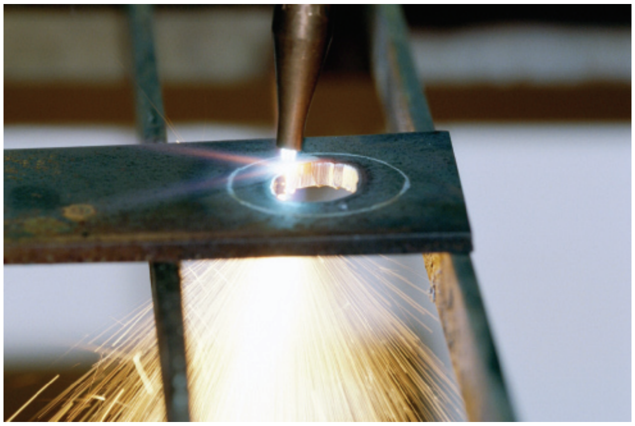
Larry Jeffus

(A)



Larry Jeffus

(B)



Larry Jeffus

(C)

FIGURE 7-58 As a hole is cut, the center may be overheated, so start the hole in the center (A) and spiral outward (B), enlarging the hole until it is full size (C).

piece of clean mild steel plate 6 in. (152 mm) long × 1/4 in. (6 mm) to 1/2 in. (13 mm) thick, you will make an oxyfuel gas cut without the preheat flame.

Place the piece of metal so that the cutting sparks fall safely away from you. With the torch lit, pass the flame over the length of the plate until it is warm, but not hot. Brace yourself and start a cut near the edge of the plate. When the cut has been established, have another student turn off the acetylene regulator. The cut should continue if you remain steady and the plate is warm enough. *Hint: Using a slightly larger tip size will make this easier.*

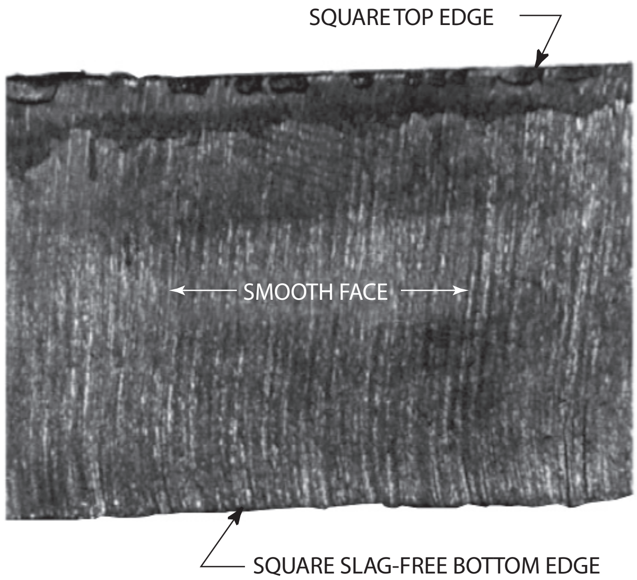
Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

THE PHYSICS OF A CUT

As a cut progresses along a plate, a record of what happened during the cut is preserved along both sides of the kerf. This record indicates to the welder what was correct or incorrect with the preheat flame, cutting speed, and oxygen pressure.

Preheat The size and number of preheat holes in a tip have an effect on both the top and bottom edges of the metal. An excessive amount of preheat flame results in the top edge of the plate being melted or rounded off. In addition, an excessive amount of hard-to-remove slag is deposited along the bottom edge. If the flame is too small, the travel speed must be slower. A reduction in speed may result in the cutting stream wandering from side to side. The torch tip can be raised slightly to eliminate some of the damage caused by too much preheat. However, raising the torch tip causes the cutting stream of oxygen to be less forceful and less accurate.

Speed The cutting speed should be fast enough so that the **drag lines** have a slight slant backward, **Figure 7-59**. If the cutting speed is too fast, the oxygen stream may not have time to go completely through the metal, resulting in an incomplete cut, **Figure 7-60**. Too slow a cutting speed results in the cutting stream wandering, thus causing gouges in the side of the cut, **Figure 7-61** and **Figure 7-62**.



Larry Jeffus

FIGURE 7-59 Correct cut.

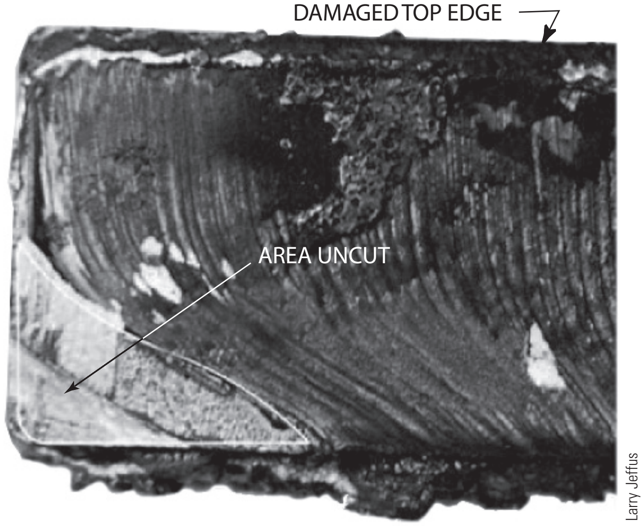


FIGURE 7-60 Too fast of a travel speed results in an incomplete cut; too much preheat and the tip is too close, causing the top edge to be melted and removed.

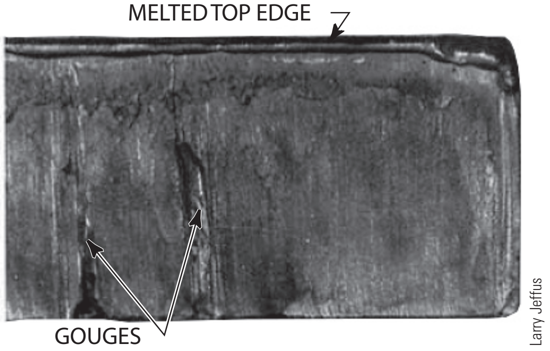


FIGURE 7-61 Too slow of a travel speed results in the cutting stream wandering, thus causing gouges in the surface; preheat flame is too close, melting the top edge.

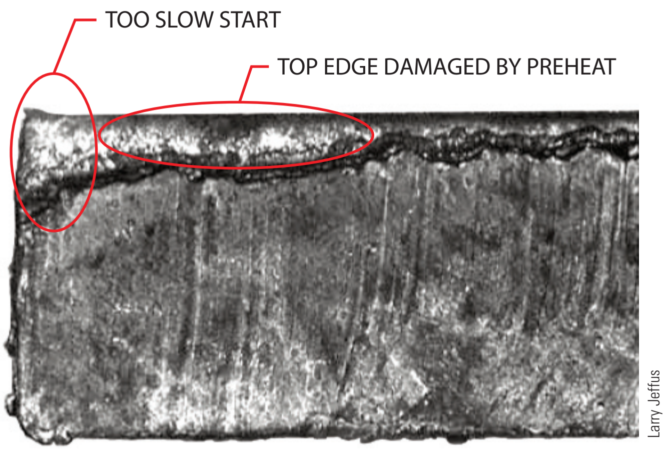


FIGURE 7-62 Too slow of a travel speed at the start; too much preheat.

Pressure A correct pressure setting results in the sides of the cut being flat and smooth. A pressure setting that is too high causes the cutting stream to expand as it leaves the tip, resulting in the sides of the kerf being slightly dished, **Figure 7-63**. When the pressure setting is too low, the cut may not go completely through the metal.

EXPERIMENT 7-2

Effect of Flame, Speed, and Pressure on a Machine Cut

Using a properly lit and adjusted automatic cutting machine, welding gloves, appropriate eye protection, protective clothing, all other required personal protective equipment, a variety of tip sizes, and one piece of mild steel plate 6 in. (152 mm) long × 1/2 in. (13 mm) to 1 in. (25 mm) thick, you will observe the effect of the preheat flame, travel speed, and pressure on the metal being cut.

Using the variety of tips, speeds, and oxygen pressures, make a series of cuts on the plate. As the cut is being made, listen to the sound it makes. Also, look at the stream of sparks coming off the bottom. A good cut should have a smooth, even sound, and the sparks should come off the bottom of the metal more like a stream than a spray, **Figure 7-64**. When the cut is complete, look at the drag lines to determine what was correct or incorrect with the cut, **Figure 7-65**.

Repeat this experiment until you know a good cut by the sound it makes and the stream of sparks. A good cut has little or no slag left on the bottom of the plate.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

EXPERIMENT 7-3

Effect of Flame, Speed, and Pressure on a Hand Cut

Using a properly lit and adjusted hand torch, welding gloves, appropriate eye protection, protective clothing, all other required personal protective equipment, and the same tip sizes and mild steel plate, repeat Experiment 7-2 to note the effects of the preheat flame, travel speed, and pressure on hand cutting.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

SLAG

The two types of **slag** produced during a cut are soft slag and hard slag. **Soft slag** is very porous, brittle, and easily removed from a cut. There is little or no unoxidized iron in it. It may be found on some good cuts. **Hard slag** may be mixed with soft slag. Hard slag is attached solidly to the bottom edge of a cut, and it requires a lot of chipping

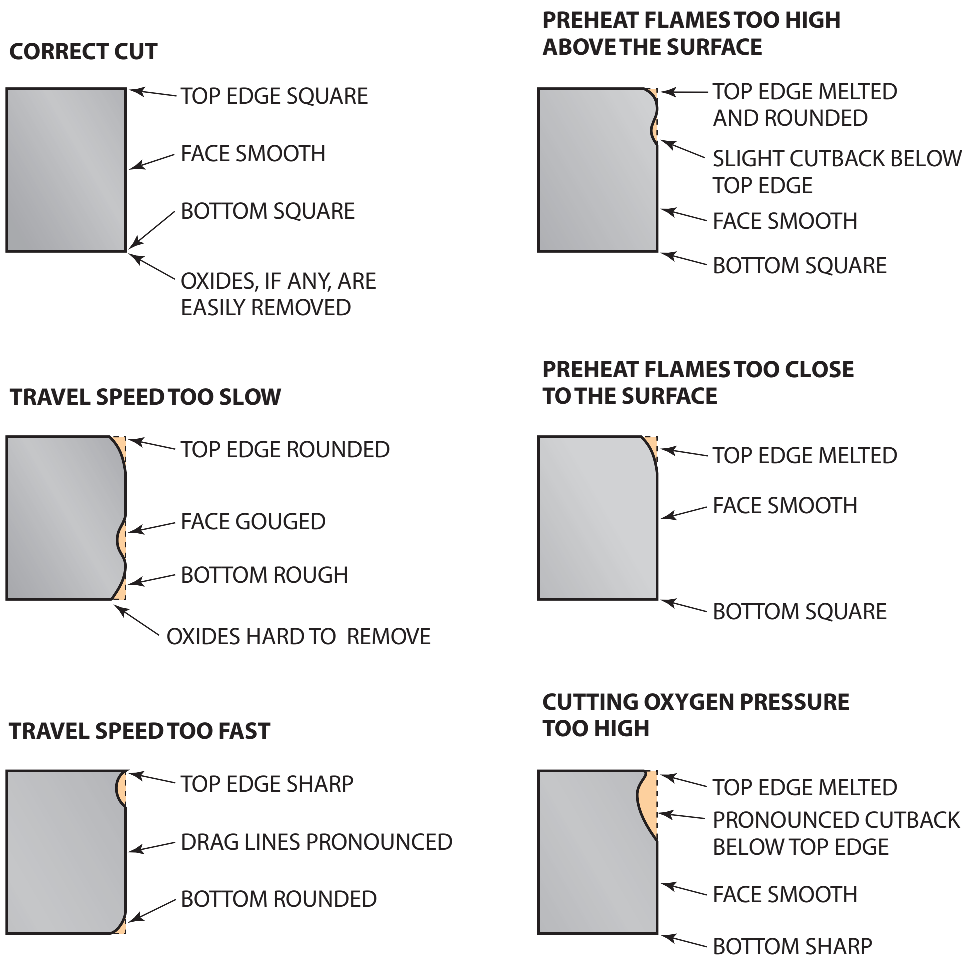


FIGURE 7-63 Profile of flame-cut plates.

FIGURE 7-64 A good cut showing a steady stream of sparks flying out from the bottom of the cut.

FIGURE 7-65 Poor cut. The slag is backing up because the cut is not going through the plate.

and grinding to be removed. There is 30% to 40% or more unoxidized iron in hard slag. The higher the unoxidized iron content, the more difficult the slag is to remove. Slag is found on bad cuts due to dirty tips, too much preheat, too slow of a travel speed, too short of a coupling distance, or incorrect oxygen pressure.

The slag from a cut may be kept off one side of the plate being cut by slightly angling the cut toward the scrap side of the cut, **Figure 7-66**. The angle needed to force the slag away from the good side of the plate may be as small as 2° or 3°. This technique works best on thin sections; on thicker sections, the bevel may show.

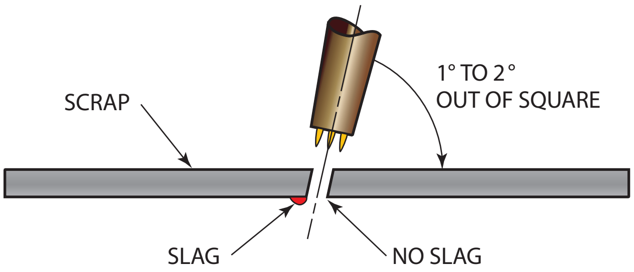


FIGURE 7-66 A slight angle on the torch will put the slag on the scrap side of the cut.

PLATE CUTTING

Low-carbon steel plate can be cut quickly and accurately ranging in thickness from thin-gauge sheet metal or thick plate sections of a foot or more. It is possible to achieve cutting speeds as fast as 32 in. per minute (13.5 mm/s), in 1/8-in. (3-mm) plate, and accuracy on machine cuts of ±3/64 in. Some very large hand-cutting torches with an oxygen cutting volume of 600 cfh (2830 L/min) can cut metal that is 4 ft (1.2 m) thick, **Figure 7-67**. However, most hand torches will not easily cut metal that is more than 7 in. (178 mm) to 10 in. (254 mm) thick.

The thicker the plate, the more difficult the cut is to make. Thin plate, 1/4 in. (6 mm) or less, can be cut and the pieces can be separated even if poor techniques and incorrect pressure settings are used. Thick plate, 1/2 in. (13 mm) or thicker, often cannot be separated if the cut is not correct. For very heavy cuts, on plate 12 in. (305 mm) or thicker, the equipment and operator technique must be near perfection or the cut will be faulty.

Plate that is properly cut can be assembled and welded with little or no postcut cleanup. Poor-quality cuts require more time to clean up than is needed to make the required adjustments to make a good weld.

CUTTING TABLE

Because of the nature of the torch cutting process, special consideration is given to the flame cutting support. Any piece being cut should be supported so the torch flame will not cut through the piece and into the table. Special cutting tables are used that expose only a small metal area to the torch flame. Some tables use parallel steel bars of metal and others use cast iron pyramids. All cutting should be set up so the flame and oxygen stream runs between the support bars or over the edge of the table.

If an ordinary welding table or another steel table is used, special care must be taken to avoid cutting through the tabletop. The piece being cut may be supported above the support table by firebrick. Another method is to cut the metal over the edge of the table.

(A)

(B)

FIGURE 7-67 Hand torches for thick sections have longer tubes (A) or have straight cutting tips (B).

TORCH GUIDES

In manual torch cutting, a guide or support is frequently used to allow for better control and more even cutting. It takes a very skilled welder to make a straight, clean cut even when following a marked line. It is even more difficult to make a radius cut to any accuracy. Guides and supports allow the height and angle of the torch head to remain constant. The speed of the cut, which is very important to making a clean, even kerf, must be controlled by the welder.

Because the torch must be held in an exact position while making any accurate cut, the welder normally supports the torch weight with the hand. Supporting the torch weight this way not only allows for more accurate work but also cuts down on fatigue. A rest, such as a firebrick, can be used to support the welder's hand so it is not directly in contact with the hot plate or in the stream of sparks from the cut.

Various types of guides can be used to guide the torch in a straight line. **Figure 7-68** shows one type of guide using angle iron. The edge of the angle is followed to make the straight cut. Bevel cuts can be made freehand with the torch, but it is very difficult to keep them uniform. More accurate bevel cuts are made by resting the torch against the angle side of an angle iron.

Special roller guides, **Figure 7-69A**, can also be attached to the torch head. The attachment holds the torch cutting tip at an exact height.

When cutting circles, a circle cutting attachment is used. **Figure 7-69B** shows how the attachment fits on the torch head. The radius can be preset to any required distance. The cutter revolves around the center point when making the cut. The roller controls the torch tip height above the plate surface.

PRACTICE 7-5

Flat, Straight Cut in Thin Plate

Using a properly lit and adjusted cutting torch and one piece of mild steel plate 6 in. (152 mm) long × 1/4 in. (6 mm) thick, you will cut off 1/2-in. (13-mm) strips.

Using a straightedge and soapstone, make several straight lines 1/2 in. (13 mm) apart. Starting at one end, make a cut along the entire length of plate. The strip must

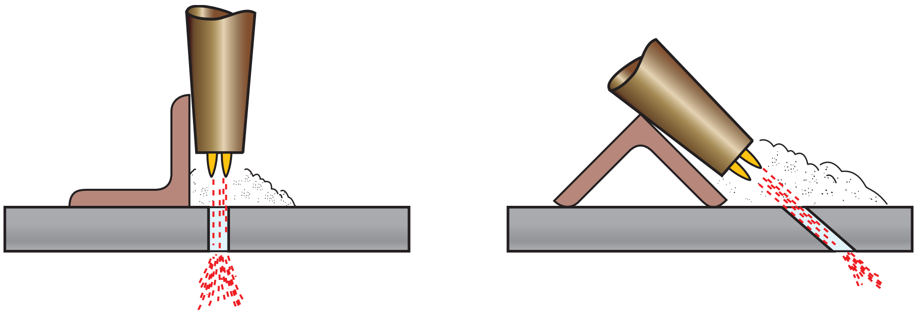


FIGURE 7-68 Using angle irons to aid in making cuts.

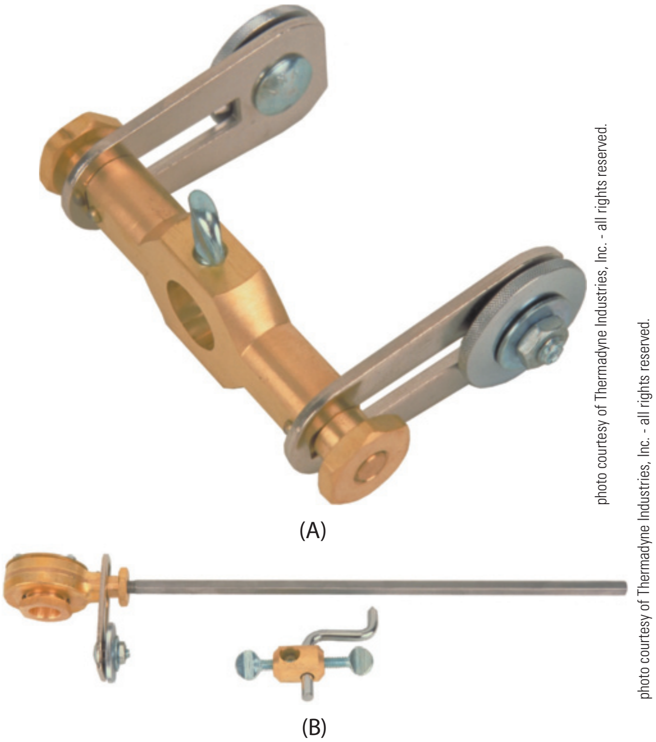


FIGURE 7-69 Devices that attach to the cutting tip to improve hand cutting. (A) Straight cutting. (B) Hole or circle cutting.

fall free, be slag-free, and be within ±3/32 in. (2 mm) of a straight line and ±5° of being square. Repeat this procedure until the cut can be made straight and slag-free. Turn off the cylinder valves, bleed the hoses, back out the pressure regulators, and clean your work area when you are finished cutting.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 7-6

Flat, Straight Cut in Thick Plate

Using a properly lit and adjusted cutting torch and one piece of mild steel plate 6 in. (152 mm) long × 1/2 in. (13 mm) thick or thicker, you will cut off 1/2-in. (13-mm) strips. *Note: Remember that starting a cut in thick plate will take longer, and the cutting speed will be slower.* Lay out, cut, and evaluate the cut as was done in Practice 7-5. Repeat this procedure until the cut can be made straight and slag-free. Turn off the cylinder valves, bleed the hoses, back out the pressure regulators, and clean your work area when you are finished cutting.

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PRACTICE 7-7

Flat, Straight Cut in Sheet Metal

Use a properly lit and adjusted cutting torch and a piece of mild steel sheet that is 10 in. (254 mm) long and 18 gauge to 11 gauge thick. Holding the torch at a very sharp leading angle, **Figure 7-70**, cut the sheet along the line. The cut must be smooth and straight with as little slag as possible. Repeat this procedure until the cut can be made flat, straight, and slag-free. Turn off the cylinder valves, bleed the hoses, back out the pressure regulators, and clean your work area when you are finished cutting.

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PRACTICE 7-8

Flame Cutting Holes

Using a properly lit and adjusted cutting torch, welding gloves, appropriate eye protection and clothing, and one piece of mild steel plate 1/4 in. (6 mm) thick, you will cut holes with diameters of 1/2 in. (13 mm) and 1 in. (25 mm). Using the technique described for piercing a hole, start

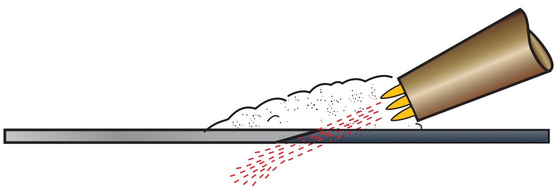

FIGURE 7-70 Cut the sheet metal at a very sharp angle.

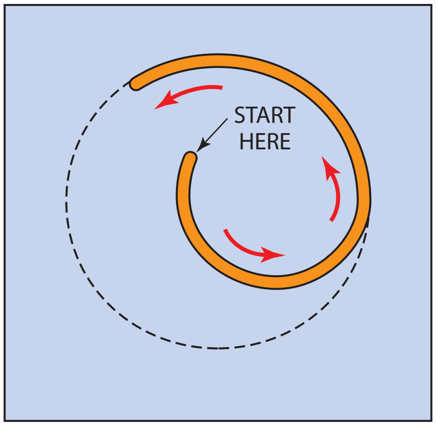

FIGURE 7-71 Start a cut for a hole near the middle.

in the center and make an outward spiral until the hole is the desired size, **Figure 7-71**. The hole must be within ±3/32 in. (2 mm) of being round and ±5° of being square. The hole may have slag on the bottom. Repeat this procedure until both small and large sizes of holes can be made within tolerance. Turn off the cylinder valves, bleed the hoses, back out the pressure regulators, and clean your work area when you are finished cutting.

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DISTORTION

Distortion is when the metal bends or twists out of shape as a result of being heated during the cutting process. This is a major problem when cutting a plate. If the distortion is not controlled, the end product might be worthless. There are two major methods of controlling distortion. One method involves making two parallel cuts on the same plate at the same speed and time, **Figure 7-72**. Because the plate is heated evenly, distortion is kept to a minimum, **Figure 7-73**.

The second method involves starting the cut a short distance from the edge of the plate, skipping other short tabs every 2 ft (0.6 m) to 3 ft (0.9 m) to keep the cut from separating. Once the plate cools, the remaining tabs are cut, **Figure 7-74**.

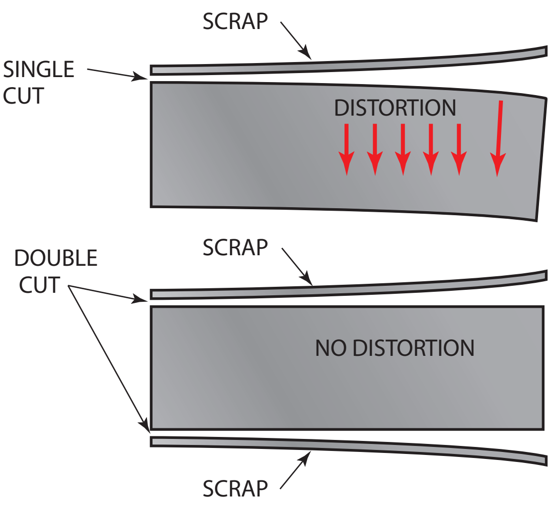

FIGURE 7-72 Making two parallel cuts at the same time will control distortion.

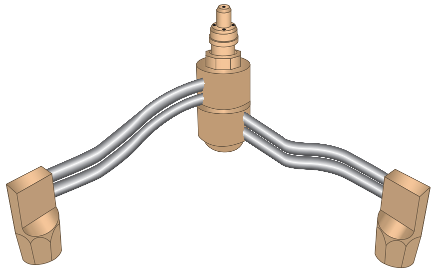

photo courtesy of Thermadyne Industries, Inc. - all rights reserved.

FIGURE 7-73 Slitting adaptor for cutting machine. It can be used for parallel cuts from 1 1/2 in. (38 mm) to 12 in. (500 mm). Ideal for cutting test coupons.

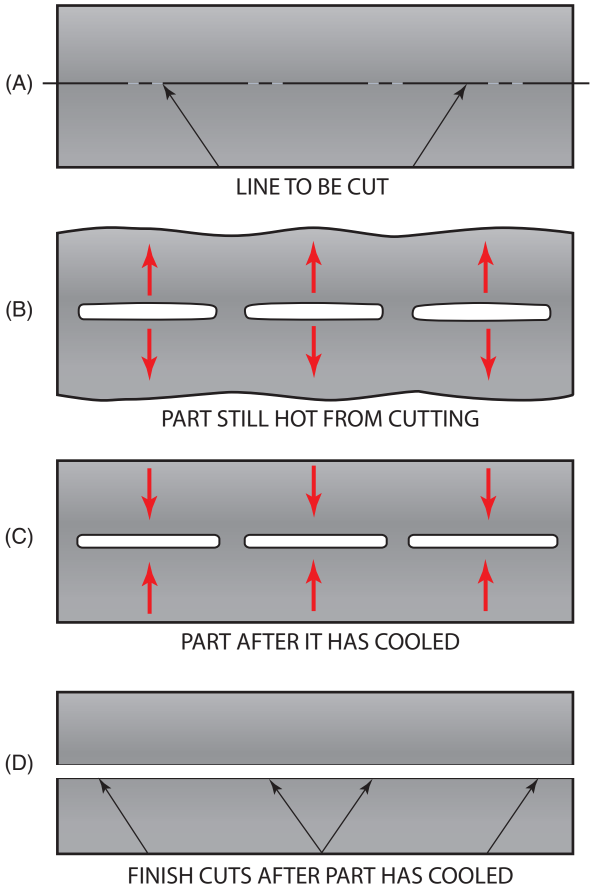

FIGURE 7-74 Steps used during cutting to minimize distortion. (A) Lay out the cut. (B) Cut along the line, periodically leaving small tabs. Once the plate has cooled, cut the tabs (C). This process reduces thermal distortion caused by the flame cutting (D).

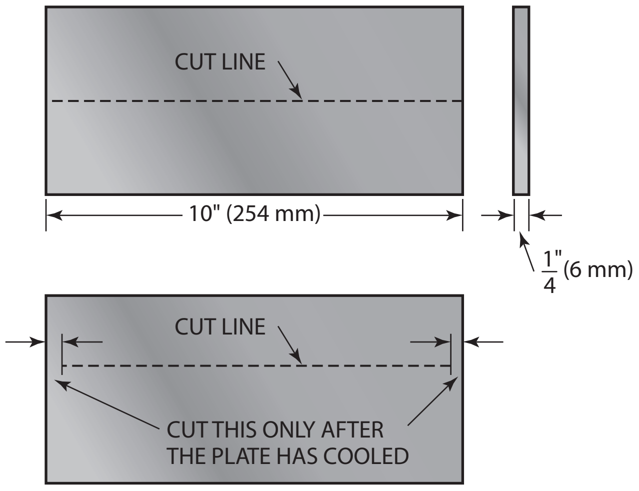

FIGURE 7-75 Making two cuts with minimum distortion. *Note: Sizes of these and other cutting projects can be changed to fit available stock.*

EXPERIMENT 7-4

Minimizing Distortion

Using a properly lit and adjusted cutting torch, welding gloves, appropriate eye protection and clothing, and two pieces of mild steel 10 in. (254 mm) long × 1/4 in. (6 mm) thick, you will make two cuts and then compare the distortion. Lay out and cut out both pieces of metal as shown in **Figure 7-75**. Allow the metal to cool, and then cut the remaining tabs. Compare the four pieces of metal for distortion.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 7-9

Beveling a Plate

Use a properly lit and adjusted cutting torch, welding gloves, appropriate eye protection and clothing, and one piece of mild steel plate 6 in. (152 mm) long × 3/8 in. (10 mm) thick. You will make a 45° bevel down the length of the plate.

Mark the plate in strips 1/2 in. (13 mm) wide. Set the tip for beveling and cut a bevel. The bevel should be within ±3/32 in. (2 mm) of a straight line and ±5° of a 45° angle. There may be some soft slag, but no hard slag, on the beveled plate. Repeat this Practice until the cut can be made within tolerance. Turn off the cylinder valves, bleed the hoses, back out the pressure regulators, and clean your work area when you are finished cutting.

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PRACTICE 7-10

Vertical Straight Cut

For this Practice, you will need a properly lit and adjusted cutting torch, welding gloves, appropriate eye protection and clothing, and one piece of mild steel plate 6 in. (152 mm) long × 1/4 in. (6 mm) to 3/8 in. (10 mm) thick marked in strips 1/2 in. (13 mm) wide and held in the vertical position. You will make a straight line cut. Make sure that the sparks do not cause a safety hazard and that the metal being cut off will not fall on any person or object.

Starting at the top, make one cut downward. Then, starting at the bottom, make the next cut upward. The cut must be free of hard slag and within ±3/32 in. (2 mm) of a straight line and ±5° of being square. Repeat these cuts until they can be made within tolerance. Turn off the cylinder valves, bleed the hoses, back out the pressure regulators, and clean your work area when you are finished cutting.

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PRACTICE 7-11

Overhead Straight Cut

Using a properly lit and adjusted cutting torch, welding gloves, appropriate eye protection and clothing, and one piece of mild steel plate 6 in. (152 mm) long × 1/4 in. (6 mm) to 3/8 in. (10 mm) thick marked in strips 1/2 in. (13 mm) wide, you will make a cut in the overhead position. When making overhead cuts, it is important to be completely protected from the hot sparks. In addition to the standard safety clothing, you should wear a leather jacket, leather apron, cap, ear protection, and a full face shield.

The torch can be angled so that most of the sparks will be blown away. The metal should fall free when the cut is completed. The cut must be within 1/8 in. (3 mm) of a straight line and ±5° of being square. Repeat this practice until the cut can be made within tolerance. Turn off the cylinder valves, bleed the hoses, back out the pressure regulators, and clean your work area when you are finished cutting.

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CUTTING APPLICATIONS

Making practice cuts on a piece of metal that will only become scrap is a good way to learn the proper torch techniques. If a bad cut is made, there is no loss. In a production shop, where each piece of metal is important, however, scrapped metal due to bad cuts decreases the shop's profits.

A number of factors that do not exist during practice cuts can affect your ability to make a quality cut on a part. The following are some of the things that can become problems when cutting:

- *Changing positions:* Often, parts are larger than can be cut from one position, so you may have to

move to complete the cut. Stopping and restarting a cut can result in a small flaw in the cut surface. If this flaw exceeds the acceptable limits, then the cut surface must be repaired before the part can be used. To avoid this problem, always try to stop at corners if the cut cannot be completed without moving.

- *Sparks:* You will often be making cuts in large plates. Even an ideal cut can create sparks that bounce around the plate surface. These sparks often find their way into your glove, under your arm, or to any other place that will become uncomfortable. Experienced welders will usually keep working if the sparks are not too large or too uncomfortable. With experience you will learn how to angle the torch, direct the cut, and position your body to minimize this problem.
- *Hot surfaces:* As you continue making cuts to complete the part, it will begin to heat up. Depending on the size of the part, the number of cuts per part, and the number of parts being cut, this heat can become uncomfortable. You may find it necessary to hold the torch farther back from the tip, but this will affect the quality of your cuts, **Figure 7-76**. Sometimes you might be able to rest your hand on a block to keep it off of the plate. Another problem with heat buildup is that it may become high enough to affect the cut quality. Heat becomes a problem when it causes the top edge of the plate to melt during a cut, as if the torch tip were too large. This is more of a problem when several cuts are being made in close proximity. Planning your cutting sequence and allowing cooling time will help control this potential problem.

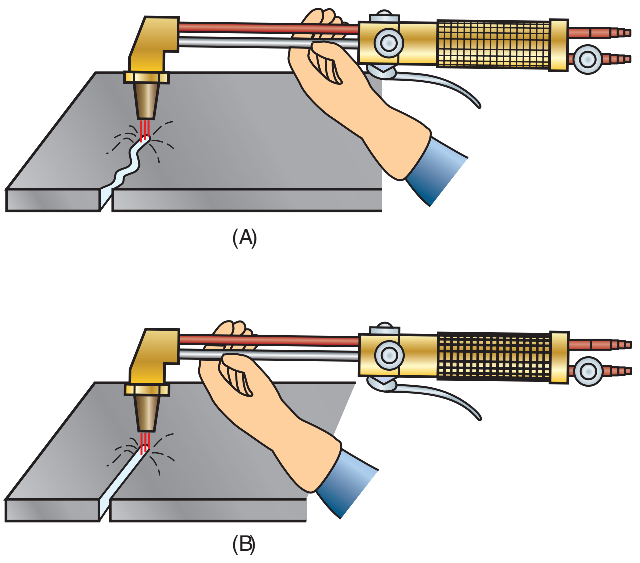

FIGURE 7-76 It is easier to make straight smooth cuts if you can brace the torch closer to the tip-like cut (B).

- *Tip cleaning:* As with any cutting, the tip will catch small sparks and become dirty or clogged. You must decide how dirty or clogged you will let the tip get before you stop to clean it. Time spent cleaning the tip reduces productivity, unfortunately. However, if you do not stop occasionally to clean up, the quality of the cut will become so bad that postcut cleanup will become excessive. It is your responsibility to decide when and how often to clean the tip.
- *Blowback:* As a cut progresses across the surface of a large plate, it may cross supports underneath the plate. During practice cuts this seldom if ever happens, but, depending on the design of the cutting table, it will occur even under the best of conditions. If the support is small, the blowback may not cover you with sparks, plug the cutting tip, or cause a major flaw in the cut surface. If the support is large, then one or all of these events can occur. If you see that the blowback is not clearing quickly, it may be necessary to stop the cut. Stopping the cut halts the shower of sparks but leaves you with a restart problem.

PRACTICE 7-12

Cutting Out Internal and External Shapes

Using a properly lit and adjusted cutting torch, welding gloves, appropriate eye protection and clothing, and one piece of plate 1/4 in. (6 mm) to 3/8 in. (10 mm) thick, you may lay out and cut out one of the sample patterns shown in **Figure 7-77**, one of the projects in Chapter 20, or any other design available.

Choose the pattern that best fits the piece of metal you have and mark it using a center punch. The exact size and shape of the layout are not as important as the accuracy of the cut. The cut must be made so that the center-punched line is left on the part and so that there is no more than 1/8 in. (3 mm) between the cut edge and the line, **Figure 7-78** and **Figure 7-79**. Repeat this practice until the cut can be made within tolerance. Turn off the cylinder valves, bleed the hoses, back out the pressure regulators, and clean your work area when you are finished cutting.

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PIPE CUTTING

Freehand pipe cutting may be done in one of two ways. On small-diameter pipe, usually smaller than 3 in. (76 mm), the torch tip is held straight up and down and moved from the center to each side, **Figure 7-80**. This technique can also be used successfully on larger pipe.

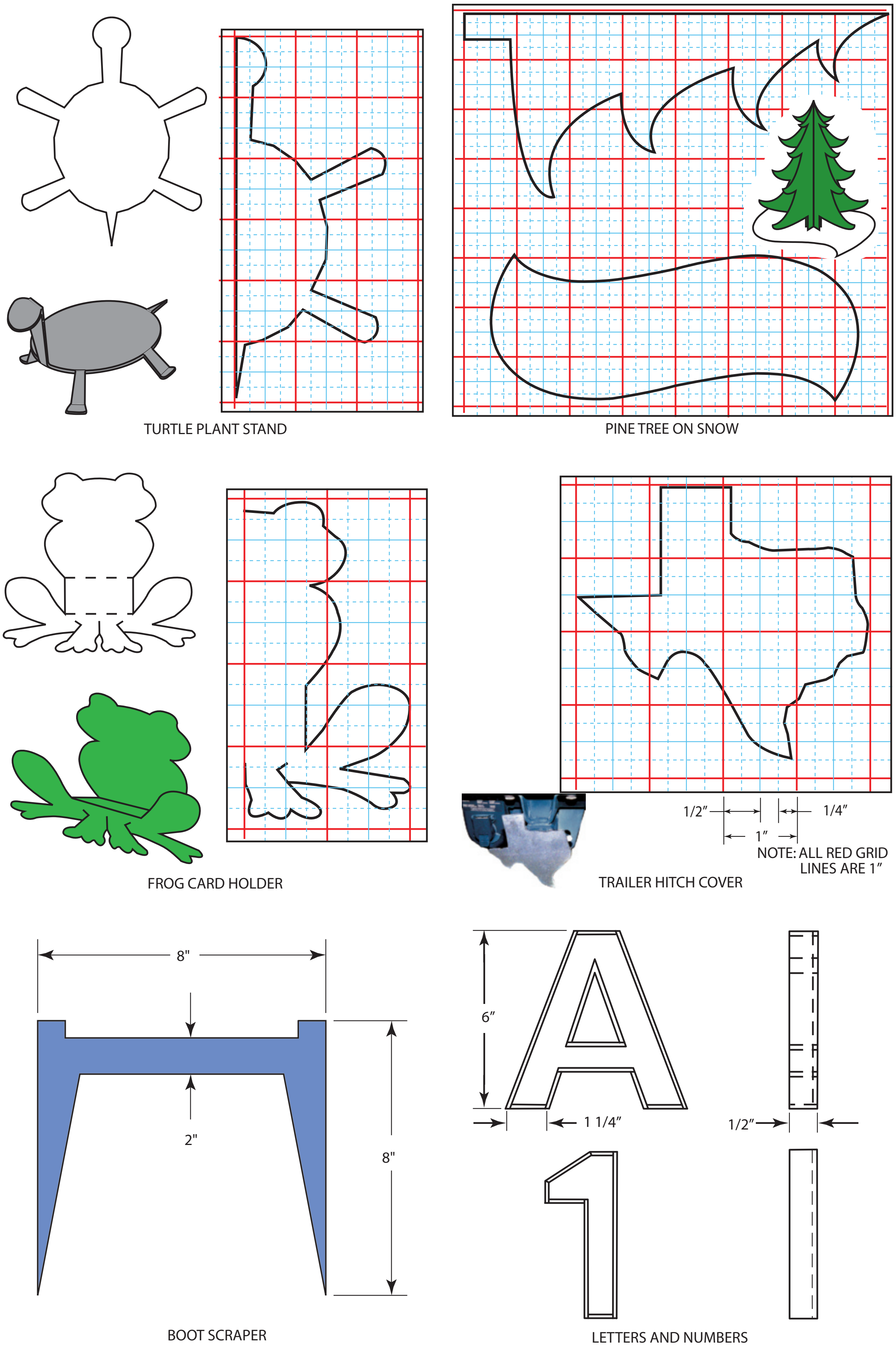

FIGURE 7-77 Suggested patterns for practice.

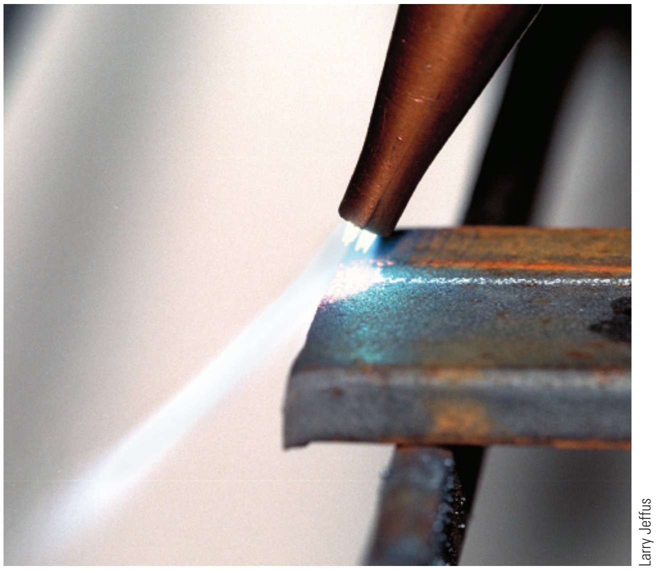

FIGURE 7-78 Beginning a cut with the torch concentrating the flame on the top edge to speed starting.

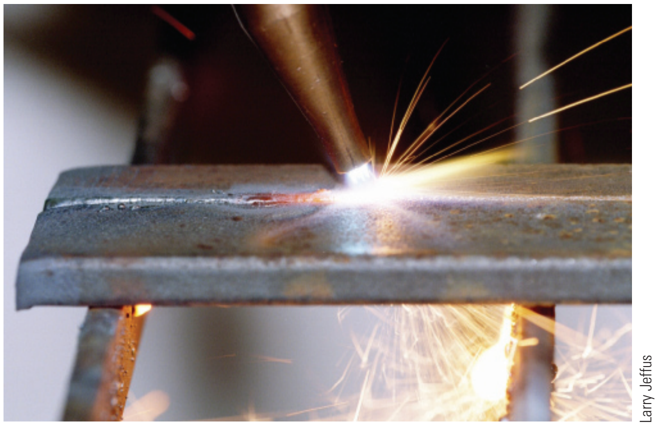

FIGURE 7-79 The torch is rotated to allow the preheating of the plate ahead of the cut. This speeds the cutting and also provides better visibility of the line being cut.

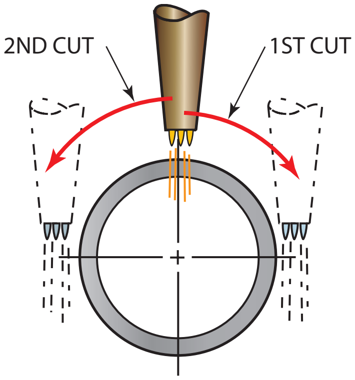

FIGURE 7-80 Small-diameter pipe can be cut without changing the angle of the torch. After the top is cut, roll the pipe to cut the bottom.

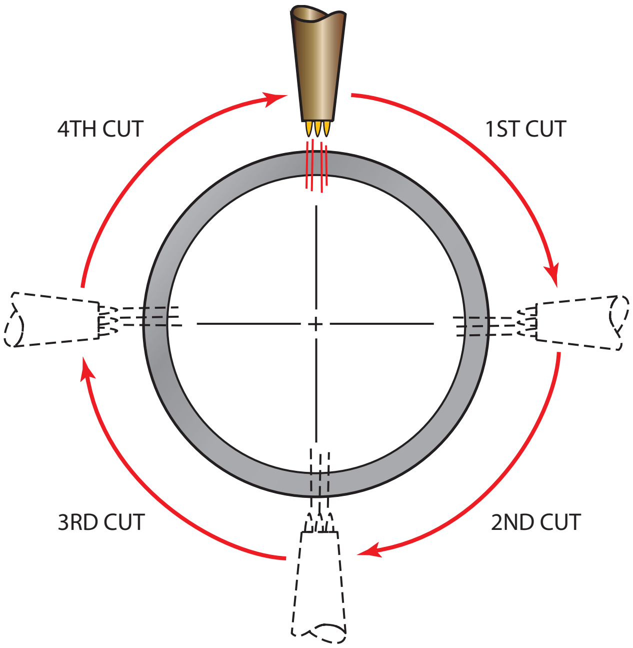

FIGURE 7-81 On large-diameter pipe, the torch is turned to keep it at a right angle to the pipe. The pipe should be cut as far as possible before stopping and turning it.

For large-diameter pipe, 3 in. (76 mm) and larger, the torch tip is always pointed toward the center of the pipe, **Figure 7-81**. This technique is also used on all sizes of heavy-walled pipe and can be used on some smaller pipe sizes.

The torch body should be held so that it is parallel to the centerline of the pipe. Holding the torch parallel helps to keep the cut square.

CAUTION

When cutting pipe, hot sparks can come out of the end of the pipe nearest you, causing severe burns. For protection from hot sparks, plug up the open end of the pipe nearest you, put up a barrier to the sparks, or stand to one side of the material being cut.

PRACTICE 7-13

Square Cut on Pipe, 1G (Horizontal Rolled) Position

Using a properly lit and adjusted cutting torch, welding gloves, appropriate eye protection and clothing, and one piece of schedule 40 steel pipe with a diameter of 3 in. (76 mm), you will cut off 1/2-in. (13-mm) -long rings.

Using a template and a piece of soapstone, mark several rings, each 1/2 in. (13 mm) wide, around the pipe. Place the pipe horizontally on the cutting table. Start the cut at the top of the pipe using the proper piercing technique. Move the torch backward along the line and

then forward; this will keep slag out of the cut. If the end of the cut closes in with slag, this will cause the oxygen to gouge the edge of the pipe when the cut is continued. Keep the tip pointed straight down. When you have gone as far as you can comfortably with the cut, release the cutting leaver and quickly flip the flame away from the pipe. Restart the cut at the top of the pipe and cut as far as possible in the other direction. Stop and turn the pipe so that the end of the cut is on top and the cut can be continued around the pipe. When the cut is completed, the ring must fall free. When the pipe is placed upright on a flat plate, the pipe must stand within 5° of vertical and have no gaps higher then 1/8 in. (3 mm) under the cut. Repeat this procedure until the cut can be made within tolerance. Turn off the cylinder valves, bleed the hoses, back out the pressure regulators, and clean your work area when you are finished cutting.

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PRACTICE 7-14

Square Cut on Pipe, 1G (Horizontal Rolled) Position

Using the same equipment, materials, and markings as described in Practice 7-13, you will cut off the 1/2-in. (13-mm) -long rings while keeping the tip pointed toward the center of the pipe.

Starting at the top, pierce the pipe. Move the torch backward to keep the slag out of the cut and then forward around the pipe, stopping when you have gone as far as you can comfortably. Restart the cut at the top and proceed with the cut in the other direction. Roll the pipe and continue the cut until the ring falls off freely. Stand the cut end of the pipe on a flat plate. The pipe must stand within 5° of vertical and have no gaps higher than 1/8 in. (3 mm). Repeat this practice until the cut can be made within tolerance. Turn off the cylinder valves, bleed the hoses, back out the pressure regulators, and clean your work area when you are finished cutting.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 7-15

Square Cut on Pipe, 5G (Horizontal Fixed) Position

With the same equipment, materials, and markings as described in Practice 7-13, you will cut off 1/2-in. (13-mm) rings, using either technique, without rolling the pipe.

Start at the top and cut down both sides as far as you can comfortably. Reposition yourself and continue the cut under the pipe until the ring falls off freely. Stand the cut end of the pipe on a flat plate. The pipe must stand within 5° of vertical and have no gaps higher than 1/8 in. (3 mm). Repeat this practice until the cut can be made within tolerance. Turn off the cylinder valves, bleed the hoses, back out the pressure regulators, and clean your work area when you are finished cutting.

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PRACTICE 7-16

Square Cut on Pipe, 2G (Vertical) Position

With the same equipment, materials, and markings as listed in Practice 7-13, you will cut off 1/2-in. (13-mm) rings, using either technique, from a pipe in the vertical position.

Place a flat piece of plate over the open top end of the pipe to keep the sparks contained, **Figure 7-82**. Start on one side and proceed around the pipe until the cut is completed. Because of slag, the ring may have to be tapped free. Stand the cut end of the pipe on a flat plate. The pipe must stand within 5° of vertical and have no gaps higher than 1/8 in. (3 mm). Repeat this practice until the cut can be made within tolerance. Turn off the cylinder valves, bleed the hoses, back out the pressure regulators, and clean your work area when you are finished cutting.

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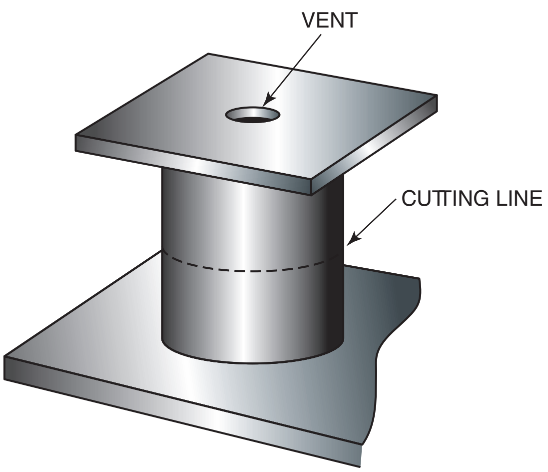

FIGURE 7-82 Place a plate on top of a short piece of pipe to keep the sparks from flying around the shop.

Summary

The oxyfuel cutting torch is one of the most commonly used (and misused) tools in the welding industry. When used properly it can produce almost machine-cut quality requiring no postcut cleanup. However, when misused the oxyfuel torch can produce some of the most difficult problems for the welding fabricator to overcome. As you learn to use the cutting torch efficiently, you can dramatically reduce postcut cleanup time and increase productivity.

Equipment setup and torch tip cleaning are essential elements required for the welder to produce quality oxyfuel cuts. Take your time each time you are setting up and preparing to make a cut; this is not wasted time. A good setup will ensure that the cut's quality will meet the fabricator's quality needs.

The travel speed for cutting will vary, depending on a number of factors such as plate thickness or the surface condition of the metal being cut. A good, clean, quality cut will progress at its own rate. Do not try to rush through too quickly. Learn to develop a sense for the cutting rate that produces the best-quality cut.

Review

1. Using Table 7-1, list the six different fuel gases in rank order according to their temperature.
2. What metals can be cut with the oxyfuel gas process?
3. What other term is used to refer to the OFC process?
4. What is a combination welding and cutting torch?
5. State one advantage of owning a combination welding and cutting torch as opposed to just having a cutting torch.
6. State one advantage of owning a dedicated cutting torch as compared to having a combination welding and cutting torch.
7. What is a mixing chamber? Where is it located?
8. Define the term *equal-pressure torch*. How does it work?
9. How does an injector-type mixing chamber work?
10. State the advantages of having two oxygen regulators on a machine cutting torch.
11. Why are some copper alloy cutting tips chrome-plated?
12. Using Table 7-4, answer the following:
    a. Oxygen pressure for cutting 1/4-in. (6-mm)-thick metal
    b. Acetylene pressure for cutting 1-in. (25-mm)-thick metal
    c. Tip cleaner size for a tip for 2-in. (51-mm)-thick metal
    d. Drill size for a tip for 1/2-in. (13-mm)-thick metal
13. What determines the amount of preheat flame requirements of a torch?
14. What can happen if acetylene is used on a tip designed to be used with propane or other such gas?
15. Why are some propane and natural gas tips made with a deep, recessed center?
16. What types of tip seals are used with cutting torch tips?
17. If a cutting tip sticks in the cutting head, how should it be removed?
18. How can cutting torch tip seals be repaired?
19. What is used to reduce the high cylinder or system gas pressure to the lower working pressure?
20. What do the two pressure gauges on a regulator show?
21. Why must the gas pressure be released and the adjusting screw backed out when welding is finished and the cylinders are turned off?
22. What should be done if the torch flashes back?
23. What is the purpose of a reverse flow valve?
24. Why must the reverse flow valve and the flashback arrestor be checked on a regular basis?
25. How can a hose be checked for leaks?
26. Why is the oxygen valve turned on before starting to clean a cutting tip?
27. Why does the preheat flame become slightly oxidizing when the cutting lever is released?
28. What causes the tiny ripples in a hand cut?
29. Why is a slight forward torch angle helpful for cutting?
30. Why should cans, drums, tanks, or other sealed containers not be opened with a cutting torch?
31. Why is the torch tip raised as the cutting lever is depressed when cutting a hole?

32. Why are the preheat holes not aligned in the kerf when making a bevel cut?

33. Sketch the proper end shape of a soapstone that is to be used for marking metal.

34. What are two methods you can use to determine what working pressure to set on the regulator?

35. What is the best way to set the oxygen pressure for cutting?

36. Why is it important to have extra ventilation and/or a respirator when cutting some used metal?

37. What factors regarding a cut can be read from the sides of the kerf after a cut?

38. What is hard slag?

39. Why is it important to make good-quality cuts?

40. When using an ordinary welding table, what can be done to avoid cutting through the tabletop?

41. Describe the methods of controlling distortion when making cuts.

42. List three things that can become a problem when cutting and affect your ability to make a quality cut.

43. How does cutting small-diameter pipe differ from cutting large-diameter pipe?

Chapter 8

Plasma Arc Cutting

OBJECTIVES

After completing this chapter, the student should be able to

- describe plasma and describe a plasma torch.
- explain how a plasma cutting torch works.
- list the advantages and disadvantages of using a plasma cutting torch.
- demonstrate an ability to set up and use a plasma cutting torch.

KEY TERMS

angular deflection
arc cutting
arc plasma
cup
deflector
dross
electrode setback
electrode tip
heat-affected zone
high-frequency alternating current
ionized gas
joules
kerf
kerf angle
nozzle
nozzle insulator
nozzle tip
pilot arc
plasma
plasma arc
plasma arc gouging
shield
stack cutting
torch standoff distance
water shroud
water table

INTRODUCTION

The plasma process was originally developed in the mid-1950s as an attempt to create an arc using argon that would be as hot as the arc created when using helium gas. The early gas tungsten arc welding process used helium gas and was called "heliarc." This early GTA welding process worked well with helium, but helium was expensive. The gas manufacturing companies had argon as a by-product from the production of oxygen. There was no good commercial market for this waste argon gas, but gas manufacturers believed there would be a good market if they could find a way to make argon weld similar to helium.

Early experiments found that by restricting the arc in a fast-flowing column of argon a plasma was formed. The plasma was hot enough to rapidly melt any metal. The problem was that the fast-moving gas blew the molten metal away. They could not find a way to control this

scattering of the molten metal, so they decided to introduce this as a cutting process, not a welding process.

Several years later, with the invention of the gas lens, plasma was successfully used for welding. Today, the plasma arc can be used for plasma arc welding (PAW), plasma spraying (PSP), plasma arc cutting (PAC), and plasma arc gouging. Plasma arc cutting is the most often used plasma process.

PAC is very popular as a result of the introduction of smaller, less expensive plasma equipment to the welding field, **Figure 8-1**. Plasma cutters have the unique ability to cut metals without making them very hot. This means that there is less distortion and heat damage than would be caused with an oxyacetylene cutting torch. Very intricate shapes can be cut out without warping.

Plasma can cut sheet metal so easily that it has become popular to use it to cut out the smallest of decorations. Most often the smallest silhouette of animals, people, buildings, and scenery used on gates, fences, barns, and so forth have been cut out using PAC, **Figure 8-2**.

Plasma cutting machines can do many of the same cutting jobs that are done with an oxyacetylene torch, but without the expense of renting gas cylinders. Small plasma cutting machines with self-contained air compressors can use 120 V electrical power from any standard wall plug or auxiliary power plug on a portable welder so they can be used almost anywhere. A portable welder can also be used to power both a compressor and a plasma cutting machine, **Figure 8-3**.

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FIGURE 8-1 Portable plasma arc cutting machine. This unit has an internal air compressor that makes it completely self-contained.

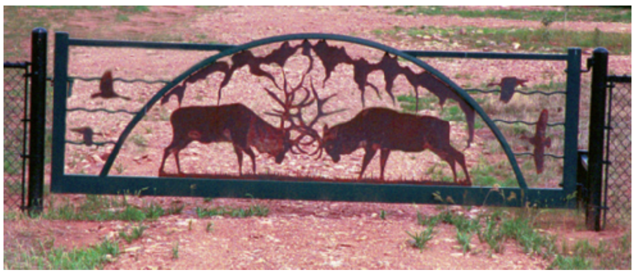

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FIGURE 8-2 Plasma cut sheet metal panels decorate this gate.

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FIGURE 8-3 Portable welder's auxiliary power plug can be used for plasma cutting and an air compressor.

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FIGURE 8-4 Plasma cuts made in steel, stainless steel, and aluminum.

Plasma machines can cut any type of metal, including aluminum, stainless steel, and cast iron, **Figure 8-4**. Plasma cutting machines can cut mild steel ranging from thin sheet metal, 28 gauge, approximately 1/64 in. (4 mm) to 6 in. (150 mm) or more, which means that the plasma torch can do most of the cutting required in any welding shop, **Figure 8-5**.

PLASMA

The word **plasma** has two meanings: it is the fluid portion of blood and it is a state of matter that is found in the region of an electrical discharge (arc). All states of matter have their own characteristics. A solid has shape and form, a liquid seeks its own level and takes the shape of its container, and a gas has no distinct shape or volume and fills its container. Plasma is a matter that has some of the characteristics of the other three shapes of matter. It is highly

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(A)

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(B)

FIGURE 8-5 (A) Precision machine cutting 2-in. (50 mm) -thick steel. (B) Machine cut of a 6 1/4-in. (155 mm) -thick stainless steel bar.

conductive and easily controlled and shaped by a magnetic field. The plasma created by an arc is an **ionized gas** that has both electrons and positive ions whose charges are nearly equal to each other.

Arc Plasma

The term **arc plasma** is defined as gas that has been heated to at least a partially ionized condition, enabling it to conduct an electric current.[1] The term **plasma arc** is the term most often used in the welding industry when referring to the arc plasma used in welding and cutting processes. There is a significant difference in how the plasma is expelled from a welding torch and a cutting torch. Plasma welding torches produce a low-velocity plasma and cutting torches produce a high-velocity plasma stream. There are far more plasma cutting torches in use than there are plasma welding torches. Therefore, only the cutting plasma troches are discussed in this chapter.

A plasma is present in any electrical discharge from the static spark from your finger in cold weather to a bolt of lightning in a thunder storm. Plasmas produce both high temperature and intense light. The amount of heat and light depends on the amount of energy in watts (volts and amps). All plasmas result from a gas being heated to a high enough temperature to convert into positive and negative ions, neutral atoms, and negative electrons. The temperature of the plasma in an unrestricted arc is approximately 11,000°F (6100°C), but the temperature created when the arc is concentrated to form a plasma is approximately 43,000°F (23,900°C), **Figure 8-6**. This is hot enough to rapidly melt or vaporize any metal it comes in contact with.

Plasma Torch

The plasma torch is a device that allows the creation and control of the plasma for welding or cutting processes. The plasma is created in both the cutting and welding torches in the same basic manner by constricting the arc into a very small gap between the electrode and nozzle. Restricting the arc and gas creates a high-energy state in the gas, converting it to the plasma used for welding and cutting.

Torch Body

The torch body, on a manual-type torch, is made of a special plastic that is resistant to high temperatures, ultraviolet light, and mechanical impact, **Figure 8-7**. The torch body is a place that provides a good grip area and protects the cable and hose connections to the head. The torch body is available in a variety of lengths and sizes. Generally, the longer, larger torches are used for the higher-capacity machines; however, sometimes you might want a longer or larger torch to give yourself better control or a longer reach. On machine torches the body is often called a barrel and may come equipped with a rack attached to its side. The rack is a flat gear that allows the torch to be raised and lowered manually to the correct height above the work, **Figure 8-8**.

Torch Head

The torch head is attached to the torch body where the cables and hoses attach to the electrode tip, nozzle tip, and nozzle. The torch and head may be connected at any angle, such as 90°, 75°, or 180° (straight), or it can be flexible. The 75° and 90° angles are popular for manual operations, and the 180° straight torch heads are most often used for machine operations. Because of the heat in the head produced by the arc, some provisions for cooling the head and its internal parts must be made. This cooling for low-power

[1]ANSI/AWS A3.0-89—An American National Standard, Standard Welding Terms and Definitions

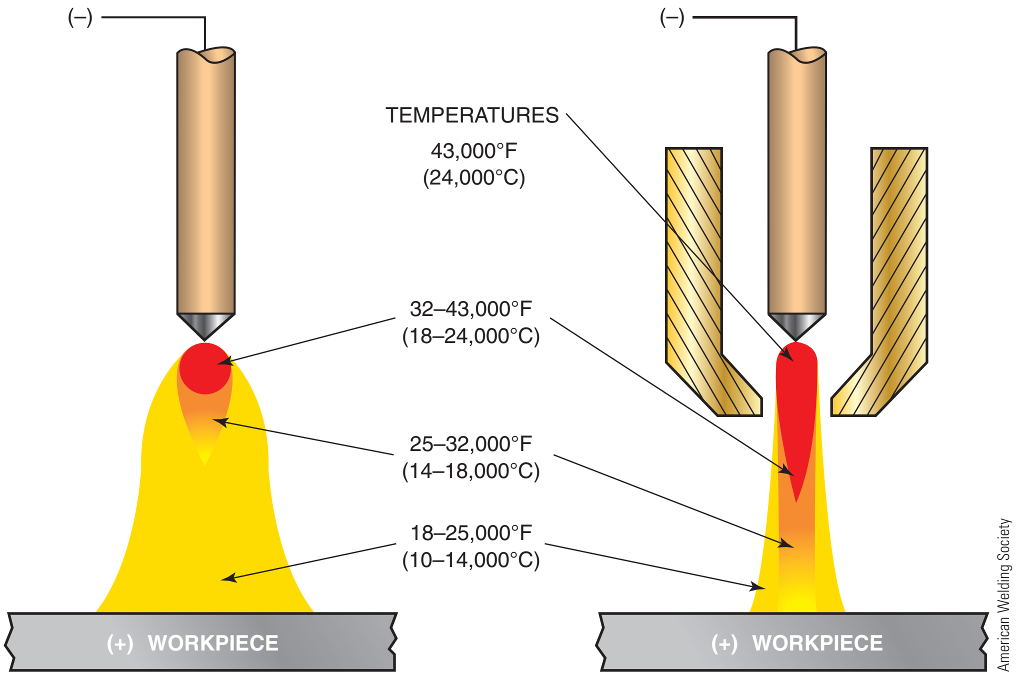

FIGURE 8-6 Approximate temperature differences between a standard arc and a plasma arc.

FIGURE 8-7 Examples of plasma arc cutting torches.

FIGURE 8-8 Plasma machine cutting torches have a rack gear just like most OFC machine torches, so they can often be installed on the same OFC cutting machines.

torches may be either by air or by water. Higher-power torches must be liquid-cooled, **Figure 8-9**.

Power Switch

Handheld torches have a manual power trigger (switch), and most have a safety guard as part of the switch to prevent accidental starting. The trigger is used to start and stop the power source, gas, and cooling water. The trigger is usually molded into the torch body. Some equipment has an automatic system that starts the plasma when the torch is brought close to the work.

Torch Parts Commonly Serviced

The electrode tip, nozzle insulator, nozzle tip, nozzle guide, and nozzle are the parts of the torch that must be replaced

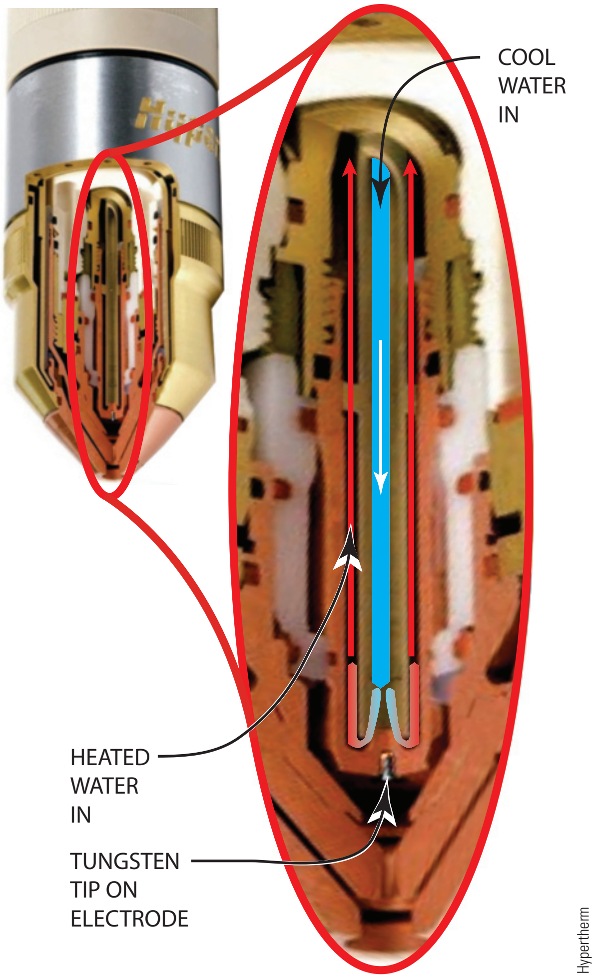

FIGURE 8-9 Large amperage plasma torches have cooling water circulating through internal passages to cool the electrode so it will last longer.

periodically as they wear out or become damaged from use, **Figure 8-10**.

CAUTION

Improper use of the torch or assembly of torch parts may result in damage to the torch body as well as the frequent replacement of these parts.

The metal parts are usually made out of copper or brass. Both metals are good conductors and are good at withstanding the heat and sparks.

Electrode Tip The **electrode tip** is made of copper with a very small tungsten, hafnium-coated tungsten, or hafnium cylinder imbedded in the end, **Figure 8-11**. Tungsten-tipped electrodes can only be used with nonoxidizing gases such as argon or nitrogen. At elevated temperatures tungsten oxidizes quickly, resulting in the failure of the electrode.

Hafnium (Hf) is a ductal metal with good electrical properties and can be used by itself as a tip for the plasma electrodes. It can also be used to coat the tiny tungsten cylinder; these electrodes are referred to as hafnium/tungsten tip electrodes. Hafnium's major benefit to plasma electrodes is its resistance to oxidation at elevated temperatures, so air can be used as the plasma gas. On hafnium/tungsten, once the hafnium coating becomes damaged the cut quality will quickly deteriorate.

Copper is used as the base metal for the electrode because it has low electrical resistance, so it does not heat up while carrying the high current needed for the plasma. Also, by using copper, the heat generated at the tip can be conducted away faster. Keeping the tip as cool as possible lengthens the life of the tip and allows for better-quality cuts for a longer time.

Nozzle Insulator The **nozzle insulator** is between the electrode tip and the nozzle tip. The nozzle insulator provides the critical gap spacing and the electrical separation of the parts. The spacing between the electrode tip and the nozzle tip is called **electrode setback**. It is critical for the proper operation of the system.

Nozzle Tip The **nozzle tip** has a small, cone-shaped, constricting orifice in the center. The electrode setback space, between the electrode tip and the nozzle tip, is where the electric current forms the plasma. The preset close-fitting parts provide the restriction of the gas in the presence of the electric current so the plasma can be generated, **Figure 8-12**. The diameter of the constricting orifice and the electrode setback are major factors in the operation of the torch. As the diameter of the orifice changes, the plasma jet action will be affected. When the setback distance is changed, the arc voltage and current flow will change. As the nozzle and electrode wear, the gap will change and the machine voltage may need to be adjusted to compensate for this change to continue making high-quality cuts.

Shield or Nozzle The **shield** or **nozzle**, sometimes called the **cup** or **deflector**, is made of ceramic or any other high-temperature–resistant substance. This helps prevent the internal electrical parts from accidental shorting and provides control of the shielding gas or water injection if they are used, **Figure 8-13**.

Water Shroud A **water shroud** nozzle may be attached to some torches. The water surrounding the nozzle tip is used to control the potential hazards of light, fumes, noise, or other pollutants produced by the process, **Figure 8-14**.

Replacement Parts The key to making accurate cuts is to inspect the parts that wear out over time and change them as needed. As parts become worn the quality of the cut will decrease, and if left their complete failure can result in significant damage to the plasma cutting torch. The electrode tip and muzzle are the two main parts that are designed to be easily replaced. Some of the other parts that must be inspected for wear and replaced periodically are the shield, swirl ring and O-ring, **Table 8-1**. Manufacturers of PAC torches have replacement part kits that contain a variety of these consumable torch parts, **Figure 8-15**.

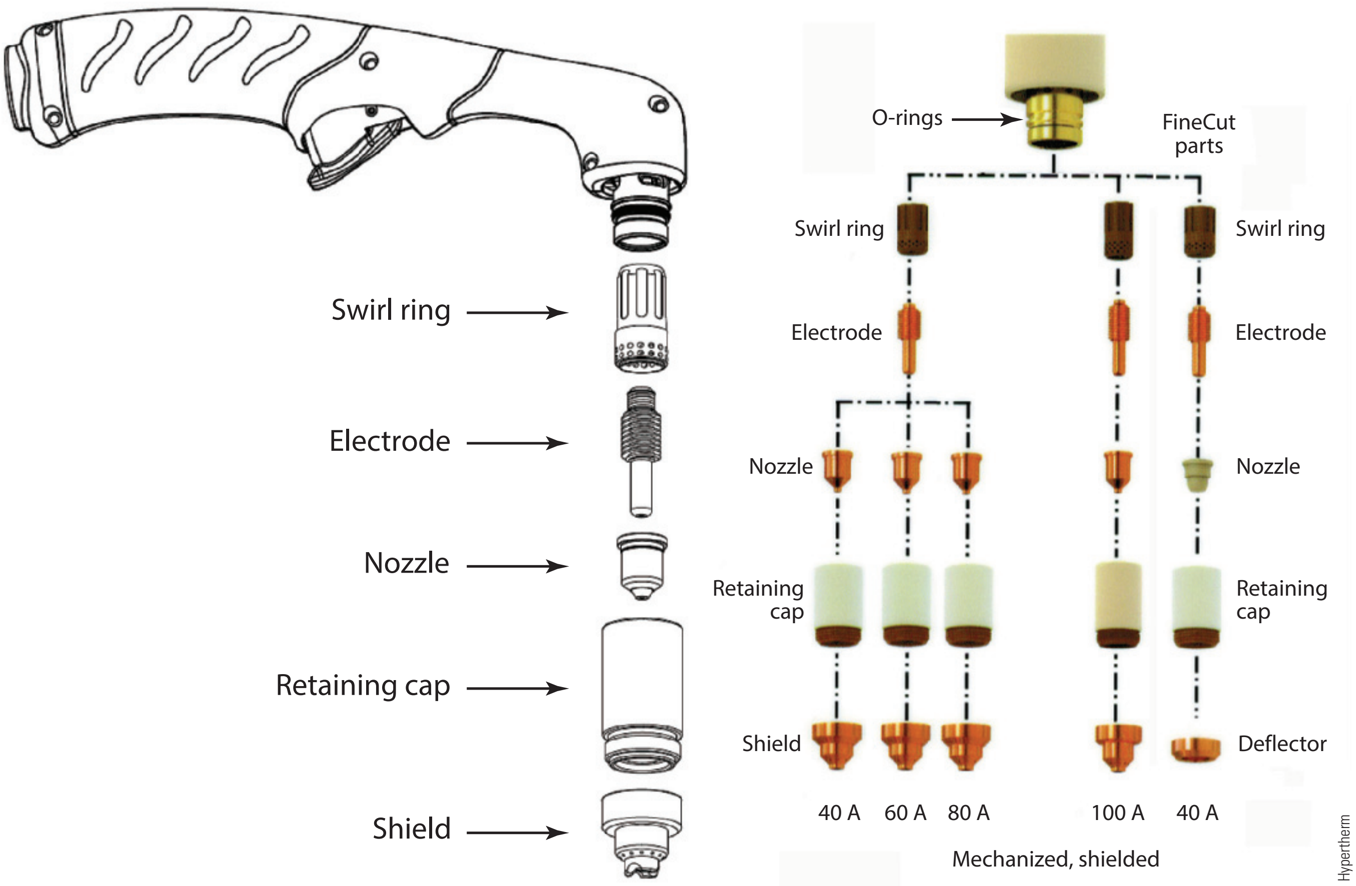

FIGURE 8-10 Replaceable torch parts.

FIGURE 8-11 Plasma electrodes come in a variety of shapes and sizes.

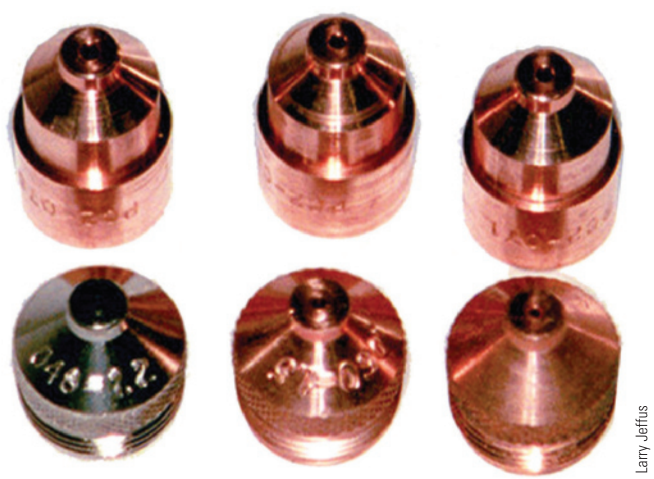

FIGURE 8-12 Nozzles are available in a variety of shapes for different types of cutting jobs.

Hoses and Power Cables

A number of power and control cables and gas and cooling water hoses may be used to connect the power supply with the torch; or with a PAC that has a self contained air compressor, only a power lead, torch lead, and work lead are needed, **Figure 8-16**. This multipart cable is usually covered to provide some protection to the cables and hoses inside and to make handling the cable easier. This covering is heat-resistant but will not prevent damage to the cables and hoses inside if it comes in contact with hot metal or is exposed directly to the cutting sparks. The cable, control wiring, and hoses should be inspected once per week for damage or leaks.

Gas Hoses

Most torches only have one gas hose running to the torch, but some larger high-amperage machine cutting torches may have two hoses. One hose carries the gas used to produce the plasma, and the other provides the shielding gas coverage.

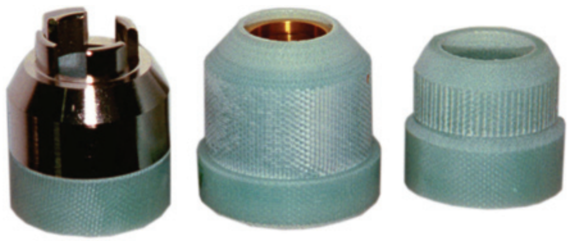

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FIGURE 8-13 Different torches use different types of nozzle tips.

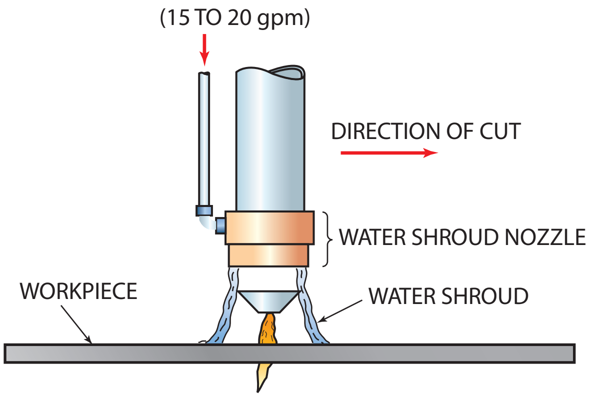

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FIGURE 8-14 Water tables keep the torch cool and reduce the sound and fumes for high-powered torches.

Inspect the consumables

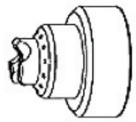
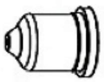
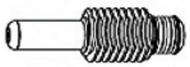
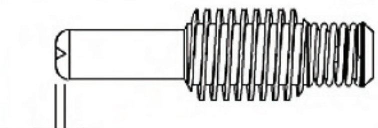
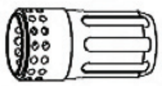
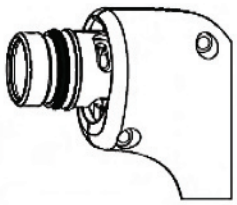
Part		Inspect	Action
	Shield or deflector	The center hole for roundness. The gap between the shield and the nozzle for accumulated debris.	Replace the shield if the hole is no longer round. Remove the shield and clean away any material.
	Nozzle	The center hole for roundness.  Good Worn	Replace nozzle if the center hole is not round.
	Electrode	 Max. 1/16 in (1.6 mm)	Replace electrode if the surface is worn or the pit depth is greater than 1/16 inch (1.6 mm) deep.
	Swirl ring	The surface inside the swirl ring for damage or wear and the gas holes for blockages.	Replace swirl ring if the surface is damaged or worn or any of the gas holes are blocked.
	Torch o-ring	The surface for damage, wear, or a lack of lubrication.	If the o-ring is dry, lubricate it and the threads with a thin layer of silicone lubricant. If the o-ring is worn or damaged, replace it.

TABLE 8-1 Plasma Torch Servicing

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FIGURE 8-15 Torch part replacement kit.

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FIGURE 8-16 Typical manual plasma arc cutting setup.

The gas hoses are made of a special heat-resistant, ultraviolet-light–resistant plastic. The hose must be sized to carry the required gas flow rate within the pressure range of the torch, and it must be free of solvents and oils that might contaminate the gas. So, if it is necessary to replace the hose because it is damaged, be sure to use the hose provided by the manufacturer or a welding supplier. If the pressure of the gas supplied is excessive, the hose may leak at the fittings or rupture.

Power Cable

The power cable must have a high-voltage–rated insulation, and it is made of finely stranded copper wire to allow for

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FIGURE 8-17 Thin strands of copper help to make the cables more flexible.

maximum flexibility of the torch, **Figure 8-17**. For all non-transfer-type torches and those that use a high-frequency pilot arc, there are two power conductors, one positive (+) and one negative (−). The size and current-carrying capacity of this cable are controlling factors in the power range of the torch. As the capacity of the equipment increases, the cable must be made large enough to carry the increased current. The larger cables are less flexible and more difficult to manipulate. To make the cable smaller on water-cooled torches, the cable is run inside the cooling water return line. Putting the power cable inside the return water line allows a smaller cable to carry more current. The water prevents the cable from overheating.

COOLANT SYSTEM

The coolant system for a plasma workstation consist of a water pump, coolant reservoir, and hoses to carry the coolant to and from the torch, **Figure 8-18**. The coolant reservoir should have a sight glass or liquid level indicator to make it possible to check that there is adequate coolant. Some systems have a safety interlock to prevent the torch from working if the coolant level is low. On large-capacity systems a heat exchanger may be added to the reservoir to help dissipate the heat and keep the coolant cool enough to do its job. From time to time the coolant reservoir must be cleaned and flushed to remove any sediment that may have collected on the bottom.

Coolant

Medium-amperage and high-amperage torches may be water-cooled. The water for cooling plasma torches should be deionized. Deionized water is free from materials that can clog the small internal openings within the torch. It is also free from conductive ions that damage the cooling system over time. When freezing is a possibility, the cooling water should also contain an approved antifreeze solution. Refer to the manufacturer's manual to see what coolant requiems your torch may need.

If cooling water is required, it must be switched on and off at the same time as the plasma power. Allowing the water to circulate continuously might result in condensation in the torch. When the power is reapplied, the water will cause internal arcing damage.

Coolant Hoses

Cooling hoses must be made of a flexible, heat-resistant, and ultraviolent light-resistant material. The hoses must be sized to allow the system pump to circulate the required

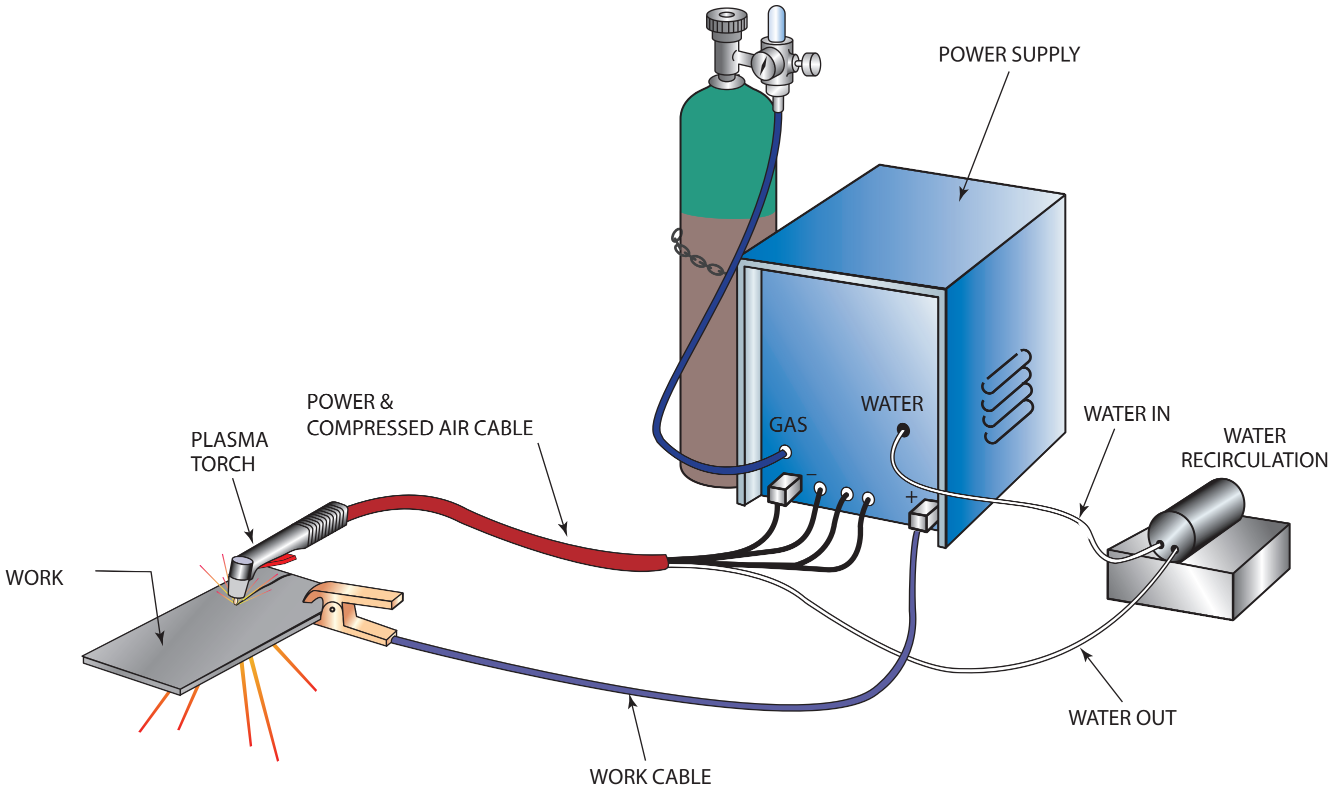

FIGURE 8-18 Inverter type plasma arc cutting power supply.

volume of coolant to keep the torch cool. Restrictions in the hose from sediment in the coolant reservoir or crimping can reduce the coolant flow. When the power cable runs inside of the coolant hose, restrictions to the flow can allow the cable to overheat. It the power cable overheats, it can melt through the coolant cable, causing a major leak. The hoses must be routinely checked for damage and leaks.

CONTROL WIRE

The control wire is a two-conductor, low-voltage, stranded copper wire. This wire connects the power switch to the power supply. This allows the welder to start and stop the plasma power and gas as needed during the cut or weld.

COMPRESSED AIR

Most small shop plasma **arc cutting** torches use compressed air to form the plasma and to make the cut. Compressed air must be clean and dry, so a filter dryer must be used to prevent contaminants like oil, dirt, or moisture from entering the plasma torch, **Figure 8-19**. Any contamination entering the torch can cause internal arcing between the electrode and the nozzle. Compressed air can be supplied by either an external compressor or an internal compressor. Some PA cutting machines have air compressors built into the power supply. These internal compressors are designed to

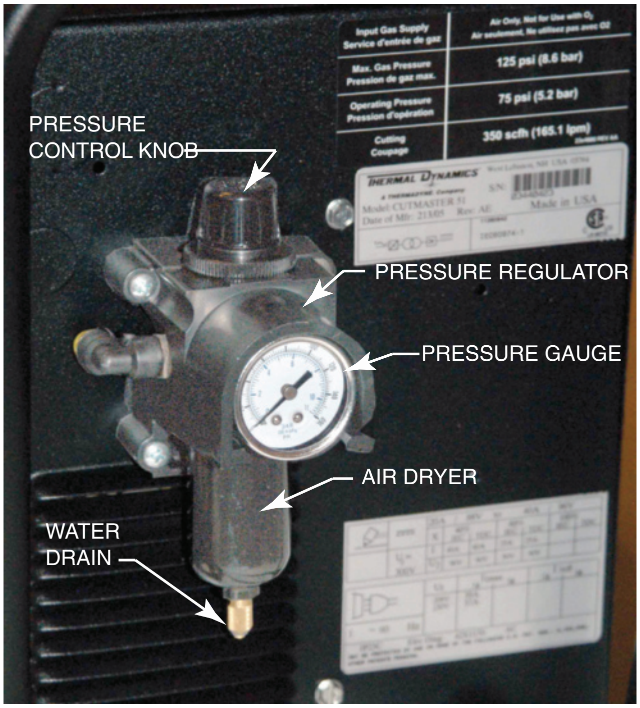

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FIGURE 8-19 Controlling the pressure is one way of controlling gas flow. Some portable plasma arc cutting machines have their own air pressure regulator and dryer. Air must be dried to provide a stable plasma arc.

provide the correct airflow and pressure. Cutting machines with internal compressors are very convenient.

POWER REQUIREMENTS

Most small plasma power supplies are inverter-type machines capable of supplying the voltage and amperages required for plasma cutting. Because inverter power supplies are smaller and highly efficient as compared to traditional power supplies, most companies have replaced the older machines.

Voltage

The production of the plasma requires a direct-current (DC), high-voltage, power supply. The voltage for a plasma arc process ranges from 50 to 200 volts closed circuit and 150 to 400 volts open circuit as compared to 18 volts to 45 volts for most types of welding. The higher electrical potential is required because the resistance of the gas increases as it is forced through a small orifice. The potential voltage of the power supplied must be high enough to overcome the resistance in the circuit for electrons to flow.

Amperage

Although the voltage is higher, the current (amperage) flow is much lower than it is with most other welding processes. Some low-powered PAC torches will operate with as low as 10 amps of current flow. High-powered plasma cutting machines can have amperages as high as 200 amps, and some very large automated cutting machines may have 1000-ampere capacities. The higher the amperage capacity, the faster and thicker they will cut.

Watts

The plasma process uses approximately the same amount of power, in watts, as a similar nonplasma process. Watts are the units of measure for electrical power. By determining the total watts used for both the nonplasma process and plasma operation, you can make a comparison. Watts used in a circuit are determined by multiplying the voltage times the amperage, **Figure 8-20**. For example, a 1/8-in. diameter E6011 electrode will operate at 18 volts and 90 amperes. The total watts used would be

$W = V \times A$
$W = 18 \times 90$
$W = 1620$ watts of power

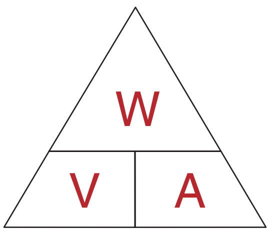

FIGURE 8-20 Ohm's Law.

A low-power PAC torch operating with only 20 amperes and 85 volts would be using a total of

$W = V \times A$
$W = 85 \times 20$
$W = 1700$ watts of power

HEAT INPUT

Although the total power used by both plasma and nonplasma processes is similar, the actual energy input into the work per linear foot is less with plasma. The very high temperatures of the plasma process allow much higher traveling rates so that the same amount of heat input is spread over a much larger area. This has the effect of lowering the **joules** per inch of heat the weld or cut will receive. **Table 8-2** shows the cutting performance of a typical plasma torch. Note the relationship among amperage, cutting speed, and metal thickness. The lower the amperage, the slower the cutting speed or the thinner the metal that can be cut.

A high travel speed with plasma cutting will result in a heat input that is much lower than that of the oxyfuel cutting process. A steel plate cut using the plasma process may have only a slight increase in temperature following the cut. It is often possible to pick up a part only moments after it is cut using plasma and find that it is cool to the touch. The same part cut with oxyfuel would be much hotter and require a longer time to cool off.

DISTORTION

Any time metal is heated in a localized zone or spot it expands in that area and, after the metal cools, it is no longer straight or flat, **Figure 8-21**. When a piece of metal is cut, there will be localized heating along the edge of the cut and, unless special care is taken, the part will not be usable as a result of its distortion, **Figure 8-22**. This distortion is a much greater problem with thin metals. By using a plasma cutter, an auto body worker can cut the thin, low-alloy sheet metal of a damaged car with little problem from distortion.

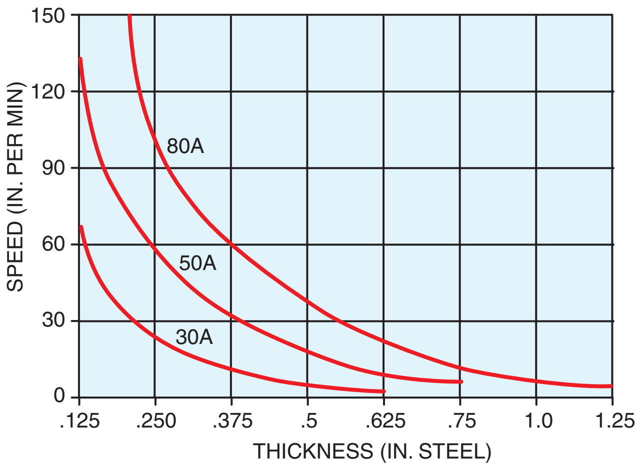

TABLE 8-2 Plasma Arc Cutting Parameters

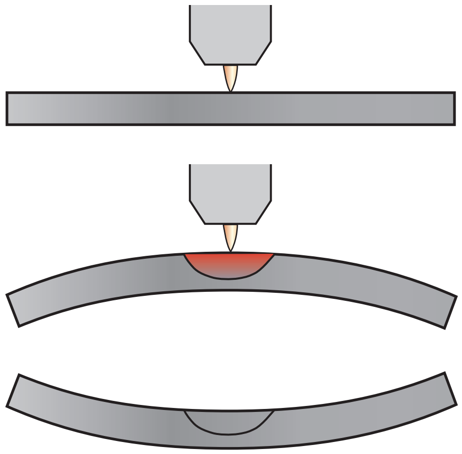

FIGURE 8-21 (A) When a flat piece of metal is heated (B) it expands, bending the edges away from the heat. (C) When the spot cools it shrinks, pulling the edges back towards the side that was heated.

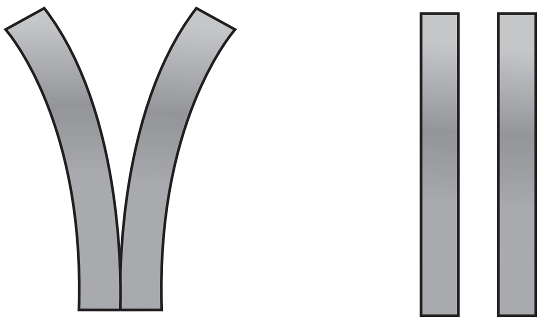

FIGURE 8-22 The heat of a torch cut causes metal to bend, but the plasma cut is so fast little or no bending occurs.

On thicker sections, the hardness zone along the edge of a cut will be reduced so much that it is not a problem. When using oxyfuel cutting of thick plate, especially higher-alloyed metals, this hardness zone can cause cracking and failure if the metal is shaped after cutting, **Figure 8-23**. Often the plates must be preheated before they are cut using oxyfuel to reduce the **heat-affected zone**. This preheating adds greatly to the cost of fabrication both in time and fuel costs. By being able to make most cuts without preheating, the plasma process will greatly reduce fabrication cost.

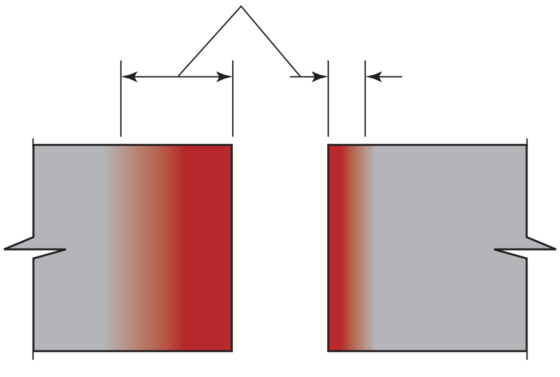

FIGURE 8-23 A smaller heat-affected zone will result in less hardness or brittleness along the cut edge.

APPLICATIONS

There are a number of variations of the conventional plasma cutting process such as:

- Duel gas plasma cutting—This process uses two different gasses, one for the plasma and one as an external shielding gas. By adding a shielding gas to protect the cut surface, it will be much cleaner and free from oxides and nitrides.
- Water injected plasma cutting—This process uses a concentrated column of water surrounding the plasma column. The water column concentrates the plasma stream by increasing its swirl, resulting in a higher density and increased temperature for faster mechanized cutting.
- Water shielding plasma cutting—The large quantity of water in this process is used to cool the torch and reduce the sound and reflected light. This mechanized cutting process uses a much higher water flow than does the water injection process.
- Precision plasma cutting—This mechanized process is used on thinner materials at slower cutting speeds so that very accurate cuts can be made.

Cutting Speed

Manufacturers have developed charts that list various types of materials, thicknesses of materials, and the recommended cutting speed. The charts may also include information regarding the maximum cutting speed for each material and thickness. The higher speeds do not produce the same high-quality cuts as the recommended cutting speeds. **Table 8-3** is an example of the types of information that can be found on cutting charts.

THINK GREEN

Poisonous Metal Fumes

Some metals, such as cadmium, chromium, and zinc, can produce poisonous metal fumes. A fume collection system can be used to capture these fumes to avoid polluting the air.

Metals

Any material that is electrically conductive can be cut using the PAC process. In a few applications nonconductive materials can be coated with conductive material so that they can be cut also. However, it is possible to make cuts in metal as thick as 7 in. (180 mm) or more. The most popular materials cut are carbon steel up to 1 in. (25 mm), stainless steel up to 7 in. (180 mm), and aluminum up to 6 in. (150 mm). These

Mild Steel

Arc Current	Arc Voltage	Pierce Delay	Material Thickness		Recommended Cut Speed		Maximum Cut Speed	
			in	mm	ipm	mm/min	ipm	mm/min
100	153	0.5	1/4	6.4	135	3429	208	5283
	155	0.5	3/8	9.5	77	1955	119	3022
	159	1.0	1/2	12.7	57	1447	88	2235
	160	1.0	5/8	15.9	40	1016	61	1549
	161	1.5	3/4	19.0	26	660	47	1193
	163	NA	1	25.4	18	457	28	711
	167	NA	1 1/4	31.8	12	305	19	482

Note: Torch-to-work distance for the following cut chart is 1/8 in (3.2 mm) for all cuts.

TABLE 8-3 Example of Manufacturer's Plasma Torch Setup for Mild Steel

are not the upper limits of the PAC process, but beyond these limits other cutting processes may be less expensive. A shop may PAC thicker material even if it is not cost-effective because it does not have ready access to the alternative process.

Other metals commonly cut using PAC are copper, nickel alloys, high-strength, low-alloy steels, and clad materials, **Figure 8-24A**. It is also used to cut stacked plates, expanded metals, screens, and other items that would require frequent starts and stops if the oxyfuel process were used, **Figure 8-24B** and **C**.

Torch Standoff Distance

The **torch standoff distance** is the distance from the nozzle tip to the work, **Figure 8-25**. This distance is very critical to producing quality plasma arc cuts. As the torch is raised,

(A) (B) (C)

FIGURE 8-24 (A) When the standoff distance is correct, as with this machine cut, almost no sparks bounce back on the cutting tip. (B) Stack cutting is when two or more plates or sheets are cut at one time. (C) Expanded metal cutting.

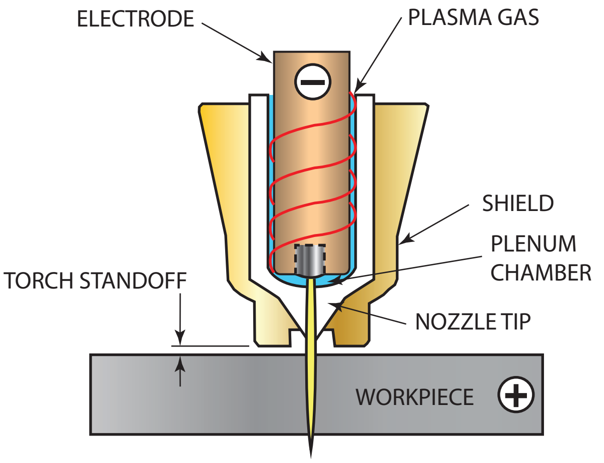

FIGURE 8-25 Conventional plasma torch terminology.

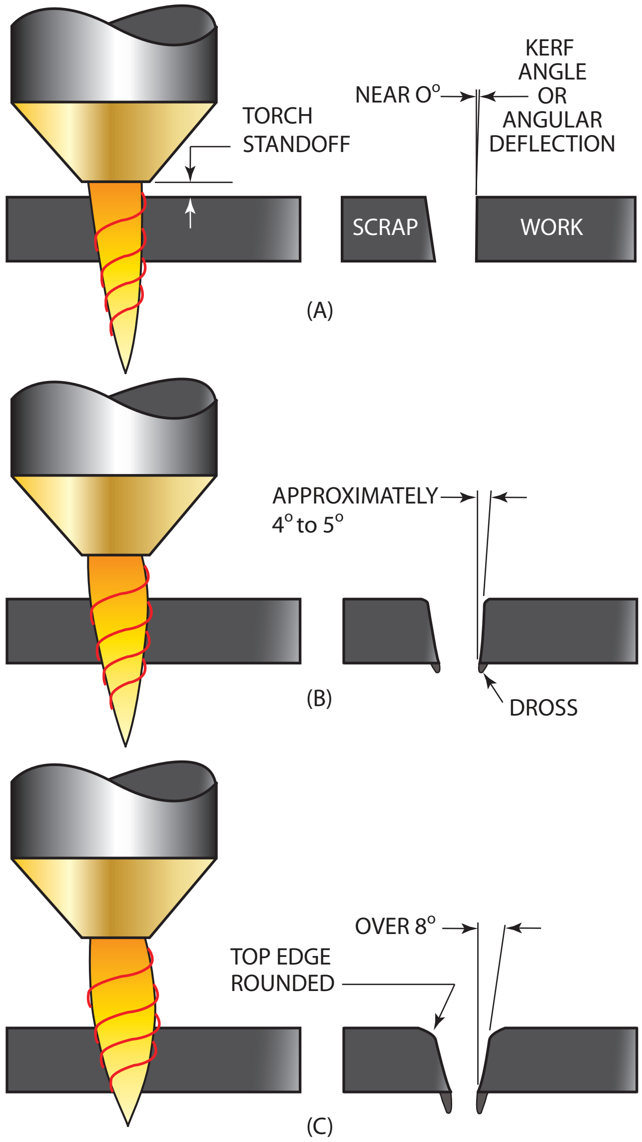

FIGURE 8-26 Examples of how standoff distance can affect the kerf angle and angular deflection.

increasing the standoff distance, the arc force is diminished. The plasma stream loses some of its stiffness and is constricted by the metal's resistance to being cut. This causes the kerf angle or angular deflection to increase. The terms ***kerf angle*** and ***angular deflection*** refer to the squareness of the cut. At the correct standoff distance the work side of the cut is nearly square, **Figure 8-26A**. As the distance increases and the plasma stream begins to be deformed, the kerf angle increases and dross begins to form on the bottom edge as the top edge starts to be rounded, **Figure 8-26B**. As the torch is raised further above the metal surface, the kerf angle begins to rapidly increase. More dross is forming on the bottom edge and the top edge is further rounded, **Figure 8-26C**. If the torch is raised further, at some point the cut will not continue all the way through the plate.

The acceptable tolerance for the angular deflection, expressed in degrees, varies depending on the metal thickness and applicable code or standard. The top edge of the plate becomes rounded, and there is more dross formation on the bottom edge of the plate.

If this distance becomes too close, the working life of the nozzle tip will be reduced. In some cases an arc can form between the nozzle tip and the metal that instantly destroys the tip.

On some torches it is possible to drag the nozzle tip along the surface of the work without shorting it out. This is a big help with any manual cutting, and especially when working on metal out of position or on thin sheet metal. **Figure 8-27** shows a typical nozzle designed to be drug along the surface being cut. Some torches use a ring spacer that clips on the outside of the torch nozzle to allow the torch to be drug. This technique can cause the nozzle tip orifice to become contaminated more quickly, so periodically spatter may need to be cleaned off.

Starting Methods

Because the electrode tip is located inside the nozzle tip and a high initial resistance to current flow exists in the gas flow before the plasma is generated, it is necessary to have a specific starting method. The most common method uses a **high-frequency alternating current** carried through the conductor, the electrode, and back from the nozzle tip.

- When the torch trigger is depressed, the plasma gas solenoid opens and the gas begins to flow through the torch tip.
- A few moments later, the high-frequency generator is turned on and the pilot arc relay contacts close.
- The high-frequency current ionizes the gas as an initial arc is created between the electrode and the nozzle, **Figure 8-28A**.
- The **pilot arc** is a low-current arc between the electrode tip and the nozzle tip within the torch head.

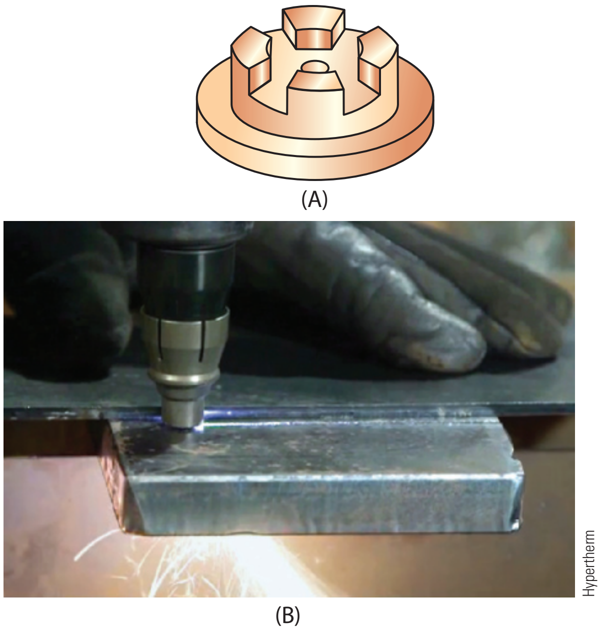

FIGURE 8-27 (A) A castle nozzle tip can be used to allow the torch to be dragged across the surface. (B) Drag cutting technique.

- When the torch gets close enough to the work, the pilot arc jumps the gap between the workpiece.
- Almost instantly after the pilot arc jumps the gap, the plasma current relay inside the power supply closes and the plasma arc is established, **Figure 8-28B**.
- As the plasma arc is established, the pilot arc relay contacts open and the pilot arc generator turns off.

NOTE

Although the pilot arc has a very low current flow, if it is left on for a long time without starting, the plasma arc can damage the nozzle tip orifice.

Kerf

The **kerf** is the space left in the workpiece as the metal is removed during a cut. The width of a PAC kerf is often wider than that of an oxyfuel cut. Several factors will affect the width of the kerf. A few of the factors are as follows:

- Standoff distance—The closer the torch nozzle tip is to the work, the narrower the kerf will be, **Figure 8-29**.
- Orifice diameter—Keeping the diameter of the nozzle orifice as small as possible will keep the kerf smaller.
- Power setting—Too high or too low of a power setting will cause an increase in the kerf width.
- Travel speed—As the travel speed is increased, the kerf width will decrease; however, the bevel on the sides and the dross formation will increase if the speeds are excessive.

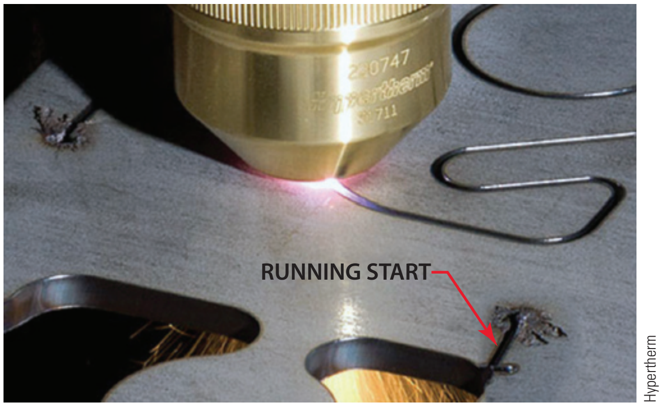

FIGURE 8-29 The narrower the kerf, the less energy input there is to the base plate.

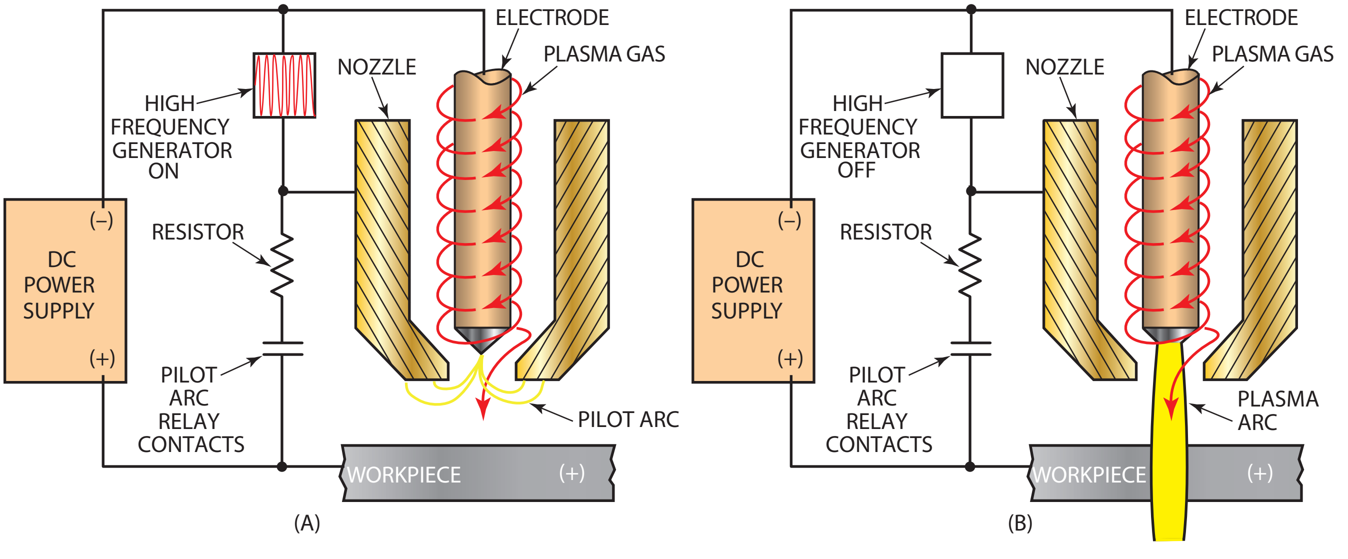

FIGURE 8-28 Plasma arc torch circuitry.

- Gas type—The type of gas or gas mixture will affect the kerf width as the gas change affects travel speed, power, concentration of the plasma stream, and other factors.
- Electrode and nozzle tip—As these parts begin to wear out from use or are damaged, the PAC quality and kerf width will be adversely affected.
- Swirling of the plasma gas—On some torches, the gas is directed in a circular motion around the electrode before it enters the nozzle tip orifice. This swirling causes the plasma stream that is produced to be more dense with straighter sides. The result is an improved cut quality, including a narrow kerf, **Figure 8-30**.
- Water injection—The injection of water into the plasma stream as it leaves the nozzle tip is not the same as the use of a water shroud. Water injection into the plasma stream will increase the swirl and further concentrate the plasma. This improves the cutting quality, lengthens the life of the nozzle tip, and makes a squarer, narrower kerf, **Figure 8-31**.

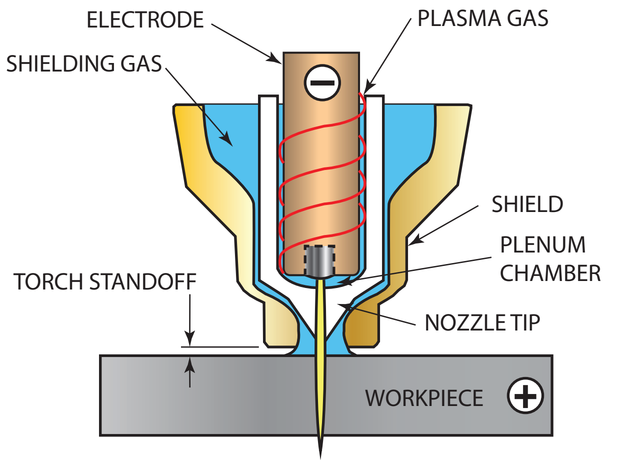

FIGURE 8-31 Water injection plasma arc cutting. Notice that the kerf is narrow and both sides are square.

Table 8-4 lists some standard kerf widths for several metal thicknesses. These are to be used as a guide for nesting of parts on a plate to maximize the material used and minimize scrap. The kerf size may vary from this depending on a number of variables with your PAC system. You should make test cuts to verify the size of the kerf before starting any large production cuts.

Because the sides of the plasma stream are not parallel as they leave the nozzle tip, there is a bevel left on the sides of all plasma cuts. This bevel angle is from 1/2° to 3° depending on metal thickness, torch speed, type of gas, standoff distance, nozzle tip condition, and other factors affecting a quality cut. On thin metals, this bevel is undetectable and offers no problem in part fabrication or finishing.

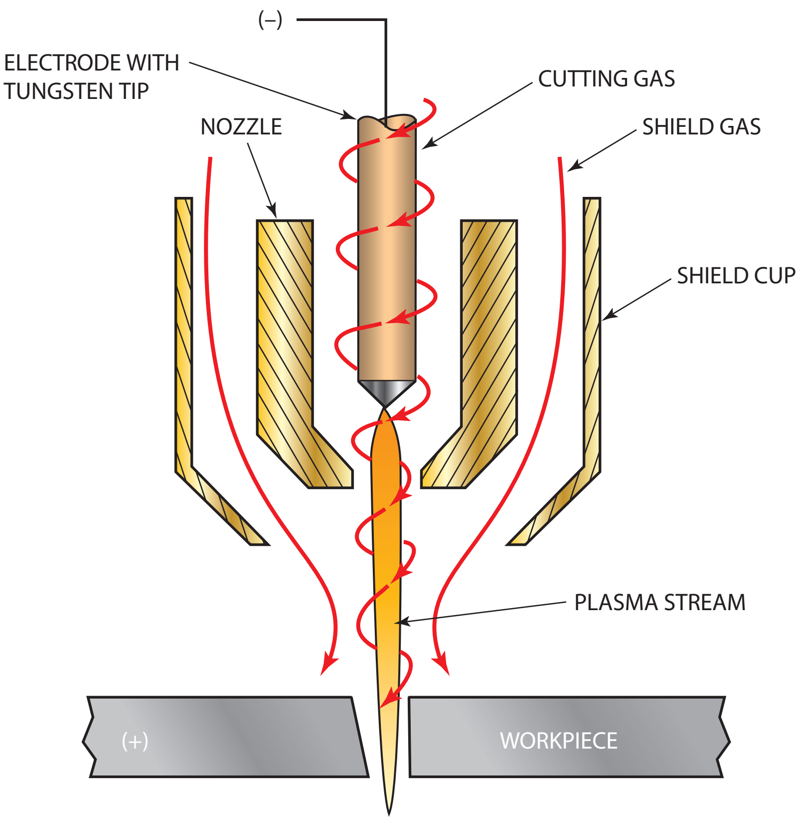

FIGURE 8-30 The cutting gas can swirl around the electrode to produce a tighter plasma column.

Process	Thickness (inches)									
	22 GA	18 GA	14 GA	10 GA	3/16	1/4	3/8	1/2	5/8	3/4
	Mild Steel Estimated Kerf Width (inches)									
100 A Shielded						0.079	0.085	0.085	0.089	0.107
85 A Shielded				0.068	0.071	0.073	0.078	0.090	0.095	0.100
80 A Shielded					0.068	0.068	0.071	0.073	0.078	0.088
65 A Shielded			0.062	0.065	0.068	0.070	0.076	0.088	0.090	0.091
60 A Shielded			0.055	0.057	0.060	0.063	0.067	0.071	0.076	0.084
45 A Shielded	0.035	0.054	0.055	0.061	0.065	0.066				

TABLE 8-4 Standard Kerf Widths for Several Metal Thicknesses

The use of a plasma swirling-type torch and the direction the cut is made can cause one side of the cut to be square and the scrap side to have all of the bevel, **Figure 8-32**. This technique is only effective provided that one side of the cut is to be scrap.

Gases

Almost any gas or gas mixture can be used today for the PAC process. Changing the gas or gas mixture is one method of controlling the plasma cut. Although the type of gas or gases used will have a major effect on the cutting performance, it is only one of a number of changes that a technician can make to help produce a quality cut. Following are some of the effects that changing the PAC gas(es) will have on the cut:

- Force—The amount of mechanical impact on the material being cut; the density of the gas and its ability to disperse the molten metal.
- Central concentration—Some gases will have a more compact plasma stream. This factor will greatly affect the kerf width and cutting speed.
- Heat content—As the electrical resistance of a gas or gas mixture changes, it will affect the heat content of the plasma it produces. The higher the resistance, the higher the heat produced by the plasma.
- Kerf width—The ability of the plasma to remain in a tightly compact stream will produce a deeper cut with less of a bevel on the sides.
- Dross formation—The dross that may be attached along the bottom edge of the cut can be controlled or eliminated.
- Top edge rounding—The rounding of the top edge of the plate can often be eliminated by correctly selecting the gas or gases that are to be used.
- Metal type—Because of the formation of undesirable compounds on the cut surface as the metal reacts to elements in the plasma, some metals may not be cut with specific gas(es).

Table 8-5 lists some of the popular gases and gas mixtures used for various PAC metals. The selection of a gas or gas mixture for a specific operation to maximize the system performance must be tested with the equipment and setup being used. With constant developments and improvements in the PAC system, new gases and gas mixtures are continuously being added to the list. In addition to the type of gas, it is important to have the correct gas flow rate for the size tip, metal type, and thickness. Too low of a gas flow will result in a cut having excessive dross and sharply beveled sides, **Figure 8-33**. Too high of a gas flow will produce a poor cut because of turbulence in the plasma stream and waste gas. A flow measuring kit can be used to test the flow at the plasma torch for more accurate adjustments.

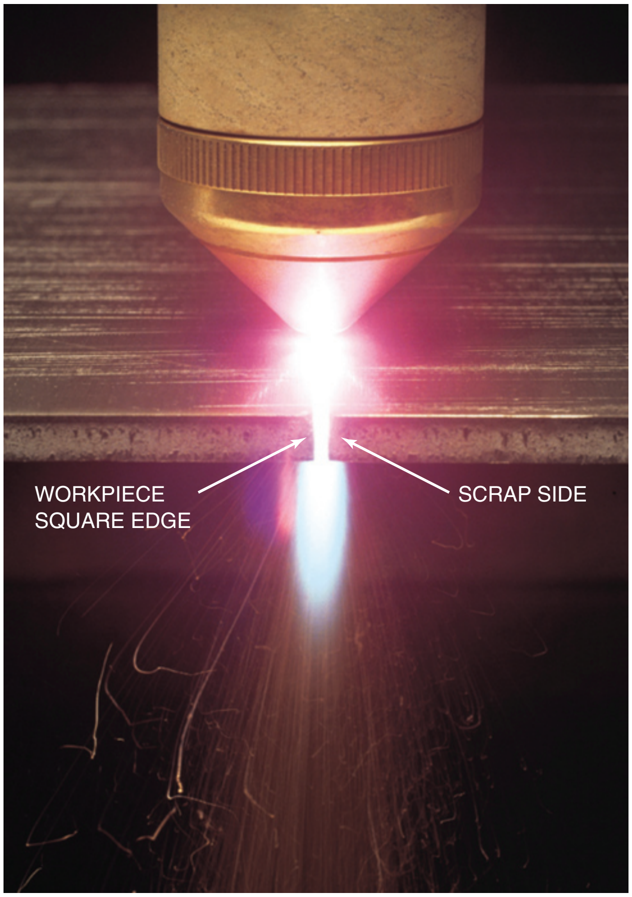

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FIGURE 8-32 Plasma arc cutting.

Metal	Gas
Carbon and low alloy steel	Nitrogen Argon with 0% to 35% hydrogen air
Stainless steel	Nitrogen Argon with 0% to 35% hydrogen
Aluminum and aluminum alloys	Nitrogen Argon with 0% to 35% hydrogen
All plasma arc gouging	Argon with 35% to 40% hydrogen

TABLE 8-5 Gases for Plasma Arc

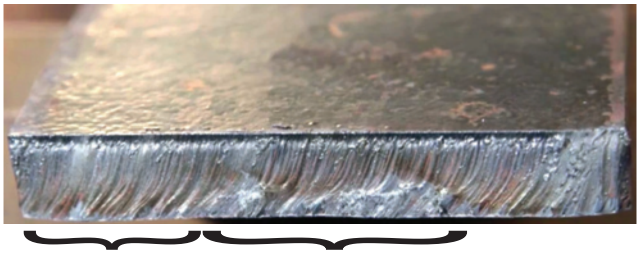


FIGURE 8-33 Consistent travel speed is required to produce a quality PA cut. This cut started out fine but became too fast for a short time.

FIGURE 8-34 Often the dross on the bottom of a cut can be easily removed, leaving a clean bottom edge for welding.

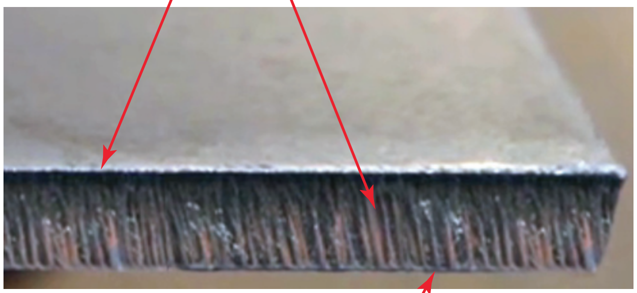


FIGURE 8-35 A good PA cut will have uniform drag lines, straight square top edge, and a dross-free bottom edge.

STACK CUTTING

Because the PAC process does not rely on the thermal conductivity between stacked parts, like the oxyfuel process, thin sheets can be stacked and cut efficiently, Figure 8-24B. With the oxyfuel **stack cutting** of sheets, it is important that there are no air gaps between layers. Also, it is often necessary to make a weld along the side of the stack for the cut to start consistently.

The PAC process does not have these limitations. It is recommended that the sheets should be held together for cutting, but this can be accomplished by using standard C-clamps. The clamping needs to be tight because if the space between layers is excessive, the sheets may stick together. The only problem that will be encountered is that, because of the kerf bevel, the parts near the bottom might be slightly larger if the stack is very thick. This problem can be controlled by using the same techniques as described for making the kerf square.

Dross

Dross is the metal compound that resolidifies and attaches itself to the bottom of a cut. This metal compound is mostly made up of unoxidized metal, metal oxides, and nitrides, **Figure 8-34**. It is possible to make cuts dross-free if the PAC equipment is in good operating condition and the metal is not too thick for the size of the torch being used. Because dross contains more unoxidized metal than most OFC slag, often it is much harder to remove if it sticks to the cut. The thickness that a dross-free cut can be made is dependent on a number of factors, including the gas(es) used for the cut, travel speed, standoff distance, nozzle tip orifice diameter, wear condition of electrode tip and nozzle tip, gas velocity, and plasma stream swirl.

Stainless steel and aluminum are easily cut dross-free. Carbon steel, copper, and nickel-copper alloys are much more difficult to cut dross-free, **Figure 8-35**.

Machine Cutting

Almost any plasma torch can be attached to some type of semiautomatic or automatic device to allow it to make machine cuts. The simplest devices are oxyfuel portable flame cutting machines that run on tracks, **Figure 8-36A**, or attach to beams and use rollers to turn the pipe under the torch head, **Figure 8-36B**. These machines are good for mostly straight beveled or circular cuts. Complex shapes can be cut with a computer-controlled pattern cutter, **Figure 8-37**.

High-powered PAC machines may have amperages up to 1000 amps. These machines must be used with

(A)

(B)

FIGURE 8-36 (A) Pipe beveling with a portable torch carriage. (B) Pipe beveling with a beam torch and pipe rollers.

FIGURE 8-37 Computer-controlled pattern cutter.

semiautomatic or automatic cutting systems. The heat, light, and other potential hazards of these machines make them unsafe for manual operations.

Large, dedicated, computer-controlled cutting machines have been built specifically for PAC systems. These machines have the high travel speeds required to produce good-quality cuts and have a high volume of production. With these machines, the operator can input the specific cutting instructions such as speed, current, gas flow, location, and shape of the part to be cut, and the machine will make the cut with a high degree of accuracy once or any number of times.

Robotic cutters are also available to perform high-quality, high-volume PAC. The advantage of using a robot is that, in most cases, the robot is capable of being set up for multitasking. When a robot is programmed, it can cut the part out, change and tool itself and weld the parts together, change the tool, and grind, drill, or paint the finished unit.

WATER TABLES

Machine cutting lends itself to the use of water cutting tables, although they can be used with most hand torches. The **water table** is used to reduce the noise level, control the plasma light, trap the sparks, eliminate most of the fume hazard, and reduce distortion.

Water tables either support the metal just above the surface of the water or they submerge the metal approximately 3 in. (76 mm) below the water's surface. Both types of water tables must have some method of removing the cut parts, scrap, and slag that build up in the bottom. Often the surface-type tables will have the PAC torch connected to a water shroud nozzle, **Figure 8-38**. By using a water shroud nozzle, the surface table will offer the same advantages to the PAC process as the submerged table offers. In most cases, the manufacturers of this type of equipment have made provisions for a special dye to be added to the water. This dye will help control the harmful light produced by the PAC. Check with the equipment's manufacturer for limitations and application of the use of dyes.

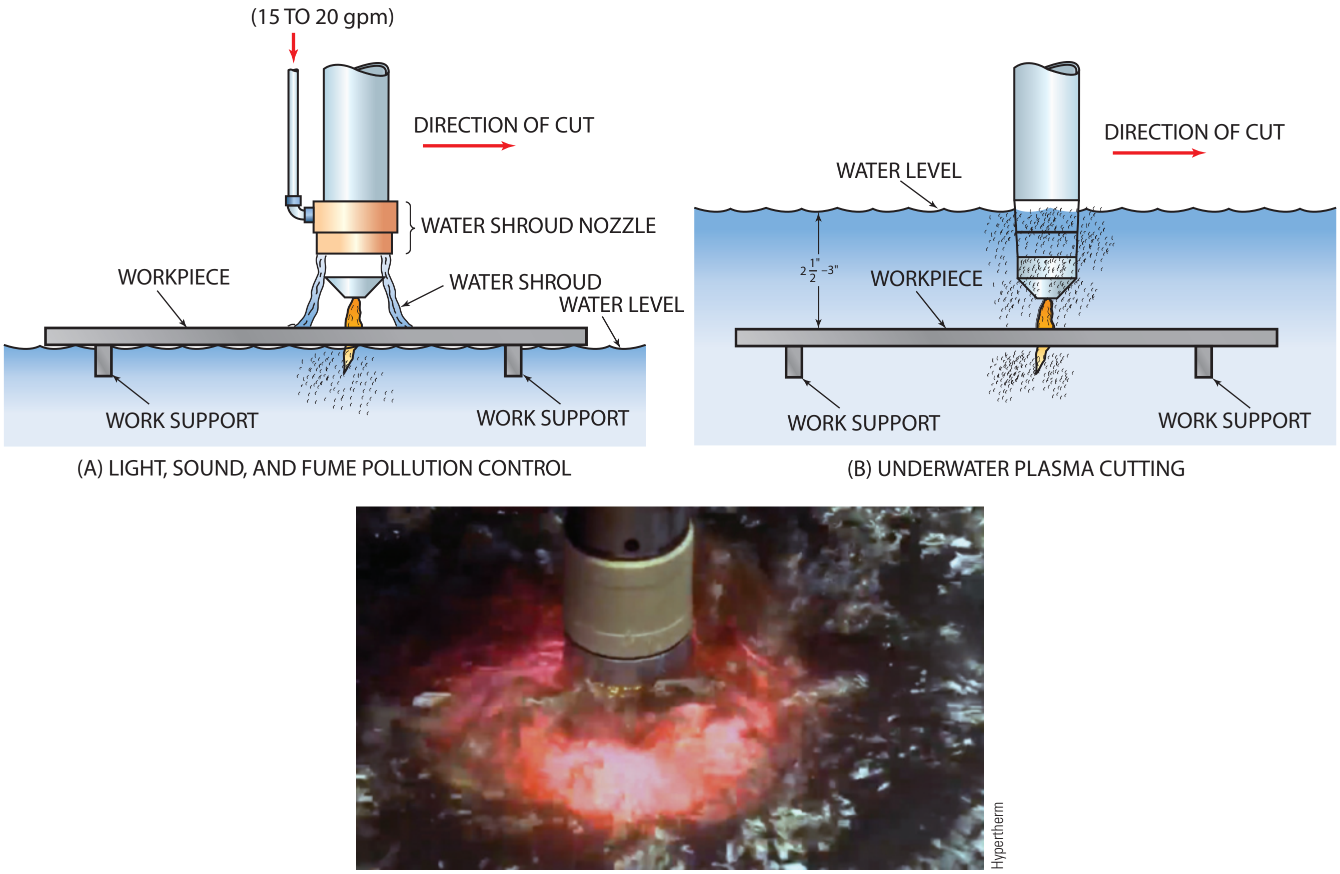
THINK GREEN

Avoid Water Contamination

Heavy metal contamination of water systems caused by rainwater washing fine metal particles away that are left by PAC can be avoided by cleaning up after outdoor cutting.

MANUAL CUTTING

Manual plasma arc cutting is the most versatile of the PAC processes, **Figure 8-39**. It can be used in all positions, on almost any surface, and on most metals. This process is limited to low-power plasma machines; however, even these machines can cut up to 1 1/2-in. (38-mm) -thick metals. The limitation to low power, 100 amperes or less, is primarily for safety reasons. The higher-powered machines have extremely dangerous open circuit voltages that can kill a person if accidentally touched.



(C)

FIGURE 8-38 A water table can be used either with (A) a water shroud or (B) underwater torches. (C) Plasma torch making a cut using a water table.

FIGURE 8-39 Manual plasma cutting equipment can be used in many different applications.

SETUP

Wearing all of the required personal protection equipment and following all of the manufacturer's safety rules, most equipment can be set up using the following steps:

- Make any adjustments and changes to the electrode tip, nozzle tip, nozzle, or other torch component before the machine power is turned on because you can be shocked if the gun trigger is accidentally activated while you are servicing these parts.

CAUTION

The open circuit voltage on a plasma machine can be high enough to cause severe electrical shock or death.

- Make sure the work clamp is connected to a clean, unpainted spot on the metal you will be cutting.
- Check to see if there is anything behind the cut that will block the sparks from falling free of the cut.
- Check to see if there is anything that will be damaged or set on fire with the sparks.
- Set the cutting amperage to maximum.
- Make a practice cut to see whether the material can be cut cleanly.
- Reduce the amperage and make another practice cut. Repeat this process until you have the amperage set as low as possible while still making a clean cut.

NOTE

Setting the amperage to the lowest possible level will extend the life of the torch parts.

SAFETY

PAC has many of the same safety concerns as most other electric welding or cutting processes. Some special concerns are specific to this process.

- Electrical shock—Because the open circuit voltage is much higher for this process than for any other, extra caution must be taken. The chance that a fatal shock could be received from this equipment is much higher than from any other welding equipment.
- Moisture—Often water is used with PAC torches to cool the torch, improve the cutting characteristic, or as part of a water table. Any time water is used it is very important that there are no leaks or splashes. The chance of electrical shock is greatly increased if there is moisture on the floor, cables, or equipment.
- Noise—Because the plasma stream is passing through the nozzle orifice at a high speed, a loud sound is produced. The sound level increases as the power level increases. Even with low-power equipment the decibel (dB) level is above safety ranges. Some type of ear protection is required to prevent damage to the operator and other people in the area of the PAC equipment when it is in operation. High levels of sound can have a cumulative effect on one's hearing. Over time, one's ability to hear will decrease unless proper precautions are taken. See the owner's manual for recommendations for the equipment in use.
- Light—The PAC process produces light radiation in all three spectrums. This large quantity of visible light, if the eyes are unprotected, will cause night blindness. The most dangerous of the lights is ultraviolet. Like other arc processes, this light can cause burns to the skin and eyes. The third light, infrared, can be felt as heat, and it is not as much of a hazard. Some type of eye protection must be worn when any PAC is in progress. **Table 8-6** lists the recommended lens shade numbers for various power-level machines.
- Fumes—This process produces a large quantity of fumes that are potentially hazardous. A specific means for removing them from the work space should be in place. A downdraft table is ideal for manual work, but some special pickups may be required for larger applications. The use of a water table and/or a water shroud nozzle will greatly help to control fumes. Often the fumes cannot be exhausted into the open air without first being filtered or treated to remove dangerous levels of contaminants. Before installing an exhaust system, you must first check with local, state, and federal officials to see if specific safeguards are required.
- Gases—Some of the plasma gas mixtures include hydrogen; because this is a flammable gas, extra care must be taken to ensure that the system is leak-proof.
- Sparks—As with any process that produces sparks, the danger of an accidental fire is always present. This is a larger concern with PAC because the sparks are often thrown some distance from the work area and the operator's vision is restricted by a welding helmet. If there is any possibility that sparks will be thrown out of the immediate work area, a fire watch must be present. A fire watch is a person whose sole job is to watch for the possible starting of a fire. This person must know how to sound the alarm and have appropriate firefighting equipment handy. **Never cut in the presence of combustible materials**.
- Operator check out—**Never operate any PAC equipment without first reading the manufacturer owner and operator's manual for the specific equipment to be used. It is a good idea to have someone who is familiar with the equipment go through the operation after you have read the manual**.

Current Range A	Minimum Shade	Comfortable Shade
Less than 300	8	9
300 to 400	9	12
400 plus	10	14

TABLE 8-6 Recommended Shade Densities for Filter Lenses

STRAIGHT CUTS

Straight cuts are the most common type of cuts made with PAC torches. You can hold the torch close to the head because it does not get as hot as an oxyacetylene torch. This will help you keep the cut smoother. One common problem with making long, straight cuts is a tendency to make the cut with a slight arc when the torch is held at a 90° angle to the cut, **Figure 8-40**. If you slide your hand along the plate surface, you can eliminate some of this arcing. Another technique to help you keep your line straight is to use a guide such as an angle iron or straight edge, **Figure 8-41**. Because there are so few sparks when cutting thin metal, you may even be able to use a square as a guide without damaging it with sparks or heat. If you use a straightedge as a guide, make sure your cut is on the line because it is difficult to see the line as it is being cut because of the size of the nozzle on many plasma torches.

PRACTICE 8-1

Flat, Straight Cuts in Thin Plate

Using a properly set up and adjusted PAC machine, proper safety protection, and one or more pieces of mild steel, stainless steel, and aluminum 6 in. (152 mm) long and 16 gauge and 1/8 in. (3 mm) thick, you will cut off strips 1/2 in. (13 mm) wide, **Figure 8-42**.

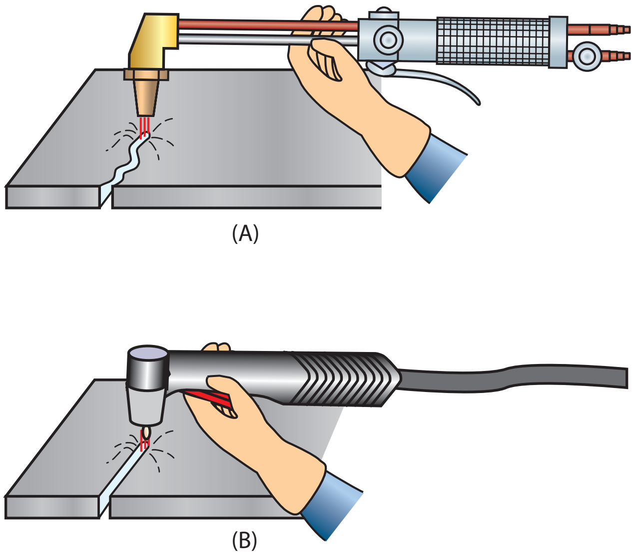


FIGURE 8-40 It is easier to make straight, smooth cuts if you can brace the torch closer to the tip, as in cut B.

FIGURE 8-41 Use an angle iron as a guide to make a straight cut.

- Starting at one end of the piece of metal that is 1/8 in. (3 mm) thick, hold the torch as close as possible to a 90° angle.
- Lower your hood and establish a plasma cutting stream.
- Move the torch in a straight line down the plate toward the other end, **Figure 8-43**.
- If the width of the kerf changes, speed up or slow down the travel rate to keep the kerf the same size for the entire length of the plate.

Repeat the cut using both thicknesses of all three types of metals until you can make consistently smooth cuts that are within ±3/32 in. (2.3 mm) of a straight line and ±5° of being square. Turn off the PAC equipment and clean your work area when you are finished cutting.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 8-2

Flat, Straight Cuts in Thick Plate

Using a properly set up and adjusted PAC machine, proper safety protection, and one or more pieces of mild steel, stainless steel, and aluminum 6 in. (152 mm) long and 1/4 in. (6 mm) and 1/2 in. (13 mm) thick, you will cut off strips 1/2 in. (13 mm) wide. Follow the same procedure as outlined in Practice 8-1.

Repeat the cut using both thicknesses of all three types of metals until you can make consistently smooth cuts that are within ±3/32 in. (2.3 mm) of a straight line and ±5° of being square. Turn off the PAC equipment and clean your work area when you are finished cutting.

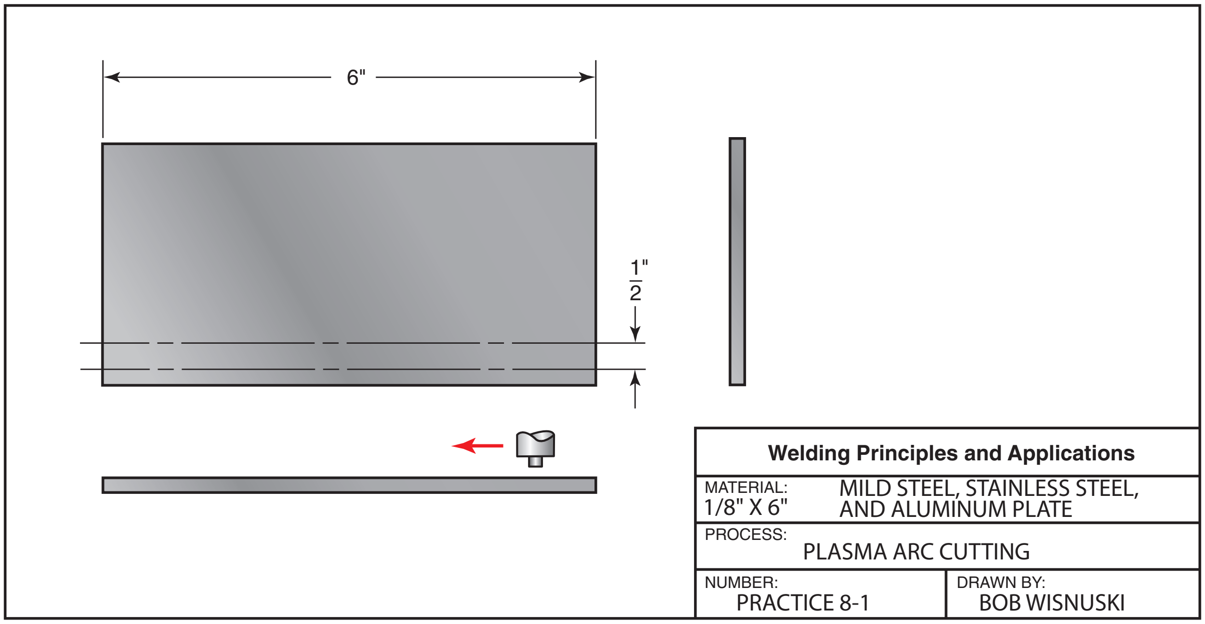
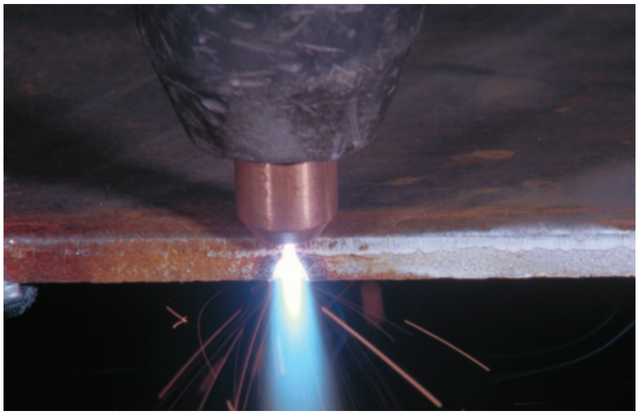


FIGURE 8-42 Straight, square plasma arc cutting.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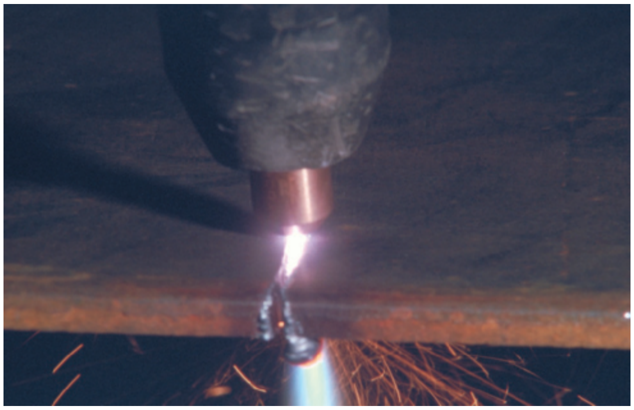
(B)


Larry Jeffus

(C)

FIGURE 8-43 (A) When the plasma cut begins, move the torch at a constant speed down the plate. (B) The spark stream should be blowing the metal away from the bottom of the plate. (C) Continue moving the torch smoothly in a straight line toward the other end of the cut.

Complete a copy of the “Student Welding Report” listed in Appendix I or provided by your instructor. ◆

PIERCING

The first step in cutting a hole or an interior shape is to pierce the plate. There are three commonly used techniques—raising the torch, running start, and angling the torch. All three techniques can be used with a manual torch, and raising the torch and running start are used with automated cutting machines. If the torch is held at just the standard height, slag from the hole will blow back onto the nozzle tip. This damage will result in significantly shortening the time that the nozzle tip can be used before it needs to be replaced.

Raising the torch is a technique in which the torch is held at the normal standoff distance. As the trigger is pulled and the piercing starts, the torch is raised so that most of the slag blowback misses the nozzle tip. When the plate is pierced, the tip is lowered back to the normal standoff distance and the cut is started.

Running start is a technique in which the torch is started moving along the plate at the same time as the plasma cutting stream is started, **Figure 8-44**. This creates a channel that guides the sparks backward away from the nozzle tip.

Angling the torch is a technique in which the torch is held at a steep angle so that as the cut starts, the slag is blown off to one side. As the piercing progresses, the torch can be rotated so it points more directly at the plate, **Figure 8-45**. Once the plate is pierced, the torch is rotated back to the 90° position.

CAUTION

When using the angle torch starting technique, you must make sure that the sparks are safely directed away from other workers in the area, equipment or material that might be damaged by the sparks, or any materials that might be ignited, thereby causing a fire.

PRACTICE 8-3

Flat Cutting Holes

Using a properly set up and adjusted PAC machine, proper safety protection, and one or more pieces of mild steel, stainless steel, and aluminum 16 gauge, 1/8 in. (3 mm), 1/4 in. (6 mm), and 1/2 in. (13 mm) thick, you will cut 1/2-in. (13-mm) and 1-in. (25-mm) holes.

- Starting with the piece of metal that is 1/8 in. (3 mm) thick, hold the torch as close as possible to a 90° angle.
- Lower your hood and establish a plasma cutting stream.
- Move the torch in an outward spiral until the hole is the desired size, **Figure 8-46**.

Repeat the hole-cutting process until both sizes of holes are made using all the thicknesses of all three types

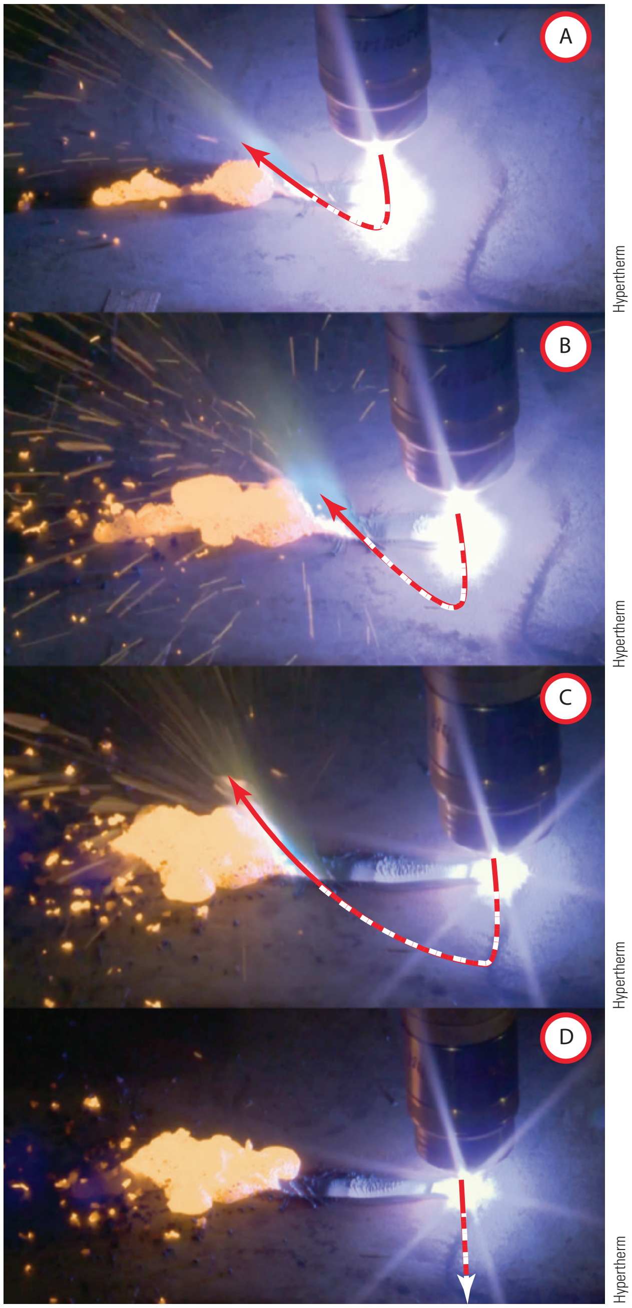


FIGURE 8-44 Running start plate piercing. (A) The surface of the plate begins to give way to the plasma cutting stream. (B) The channel that was started is made deeper into the plate. (C) As the channel is made deeper, the plasma stream loses some of its force, and the slag begins to build up at the trailing edge of the channel. (D) The plasma stream breaks through the plate, and the spark stream no longer is flowing out of the back of the channel.

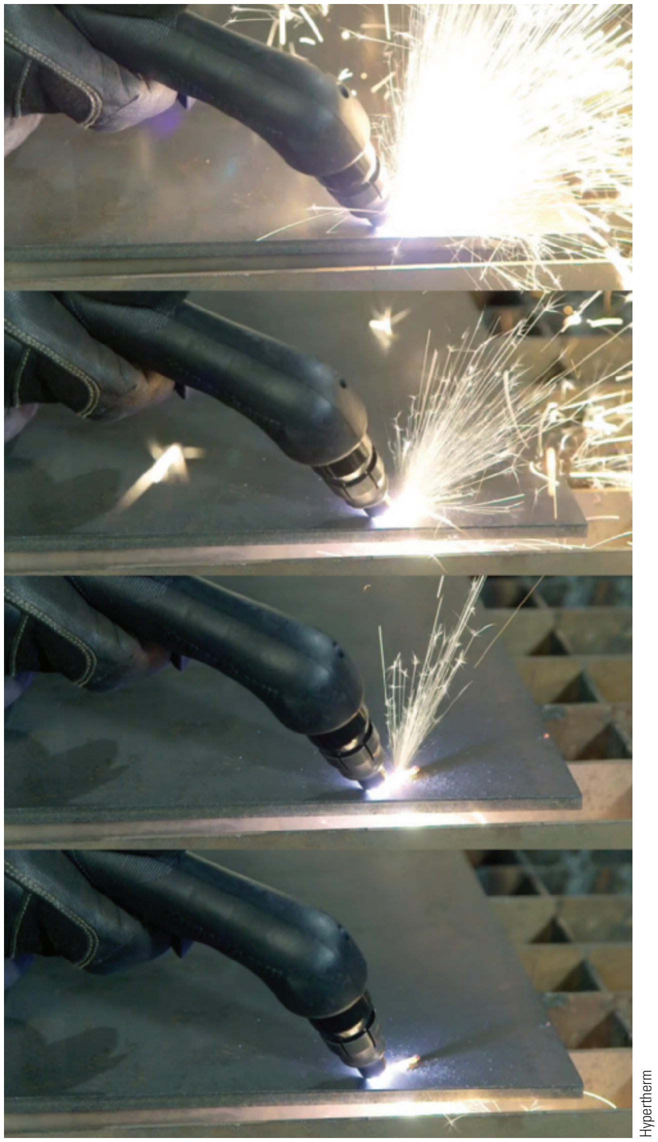


FIGURE 8-45 Angling the torch plate piercing.

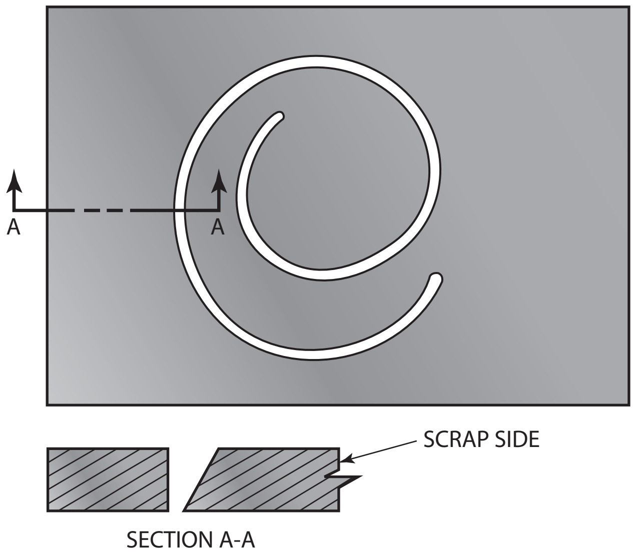


FIGURE 8-46 When cutting a hole, spiral the torch outward in a counterclockwise direction.

of metals and you can make consistently smooth cuts that are within ±3/32 in. (2.3 mm) of being round and ±5° of being square. Turn off the PAC equipment and clean your work area when you are finished cutting.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 8-4

Beveling of a Plate

Using a properly set up and adjusted PAC machine, proper safety protection, and one or more pieces of mild steel, stainless steel, and aluminum 6 in. (152 mm) long and 1/4 in. (3 mm) and 1/2 in. (6 mm) thick, you will cut a 45° bevel down the length of the plate.

- Starting at one end of the piece of metal that is 1/4 in. (3 mm) thick, hold the torch as close as possible to a 45° angle, Figure 8-41.
- Lower your hood and establish a plasma cutting stream.
- Move the torch in a straight line down the plate toward the other end, **Figure 8-47**.

Repeat the cut using both thicknesses of all three types of metals until you can make consistently smooth cuts that are within ±3/32 in. (2.3 mm) of a straight line and ±5° of a 45° angle. Turn off the PAC equipment and clean your work area when you are finished cutting.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PLASMA ARC GOUGING

Plasma arc gouging is a process that is similar to that of air carbon arc gouging in that a U-groove can be cut into the metal's surface. Plasma arc gouging can be used to remove weld defects, **Figure 8-48A**, remove damaged parts for repair work, **Figure 8-48B**, making a J-groove or U-groove to prepare the plate for welding, **Figure 8-48C**, and many other applications. An advantage of using PA cutting to remove a weld is that any slag trapped in the weld will not affect the PAC gouging process, **Figure 8-49**.

The torch is set up with a less concentrated plasma stream. This will allow the washing away of the molten metal instead of thrusting it out to form a cut. The torch is held at an approximately 45° angle to the metal surface, **Figure 8-50**. Once the groove is started, it can be controlled by the rate of travel, torch angle, and side-to-side torch movement.

Plasma arc gouging is effective on most metals. Stainless steel and aluminum are especially good metals to gouge because there is almost no cleanup. The groove is clean, bright, and ready to be welded. Plasma arc gouging is especially beneficial with these metals because there is no reasonable alternative available. The only other process that can leave the metal ready to weld is to have the groove machined, and machining is slow and expensive compared to plasma arc gouging.

It is important to try to not remove too much metal in one pass. The process will work better if small amounts are removed at a time. If a deeper groove is required, multiple gouging passes can be used.

Plasma gouging can produce a great deal of heat, which can overheat the welder's hand even with a good leather glove. This problem is even more significant because most hand plasma torches are relatively short. Some manufacturers have heat shields that can be attached to the torch to protect the welders hand from this heat, **Figure 8-51**.

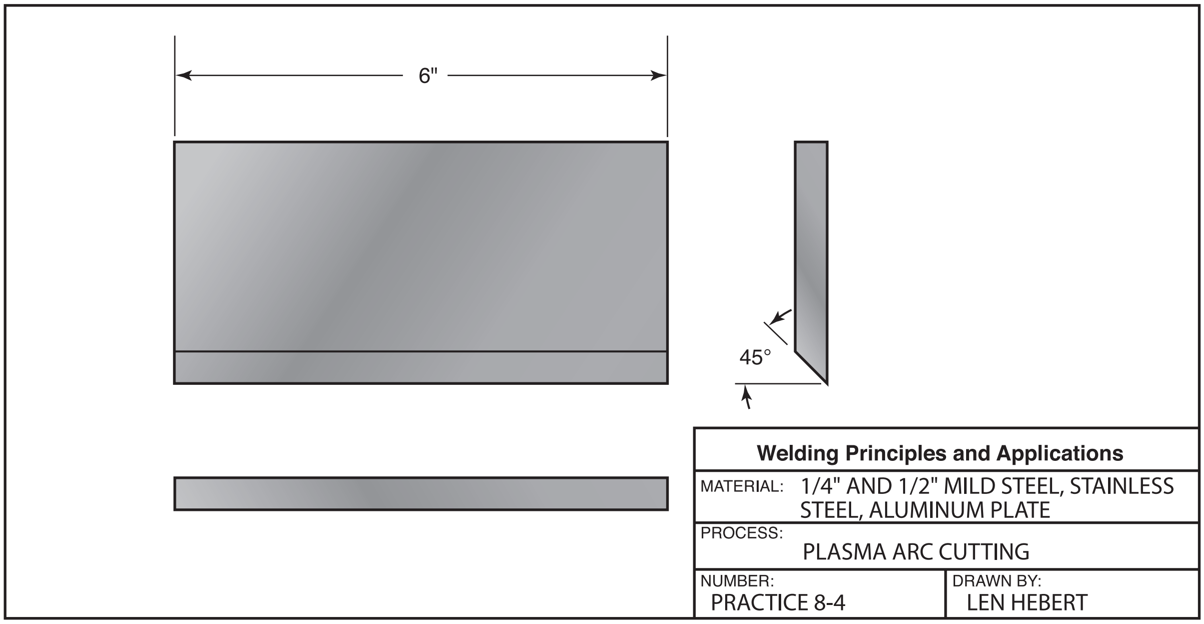


FIGURE 8-47 Beveled plasma arc cutting.

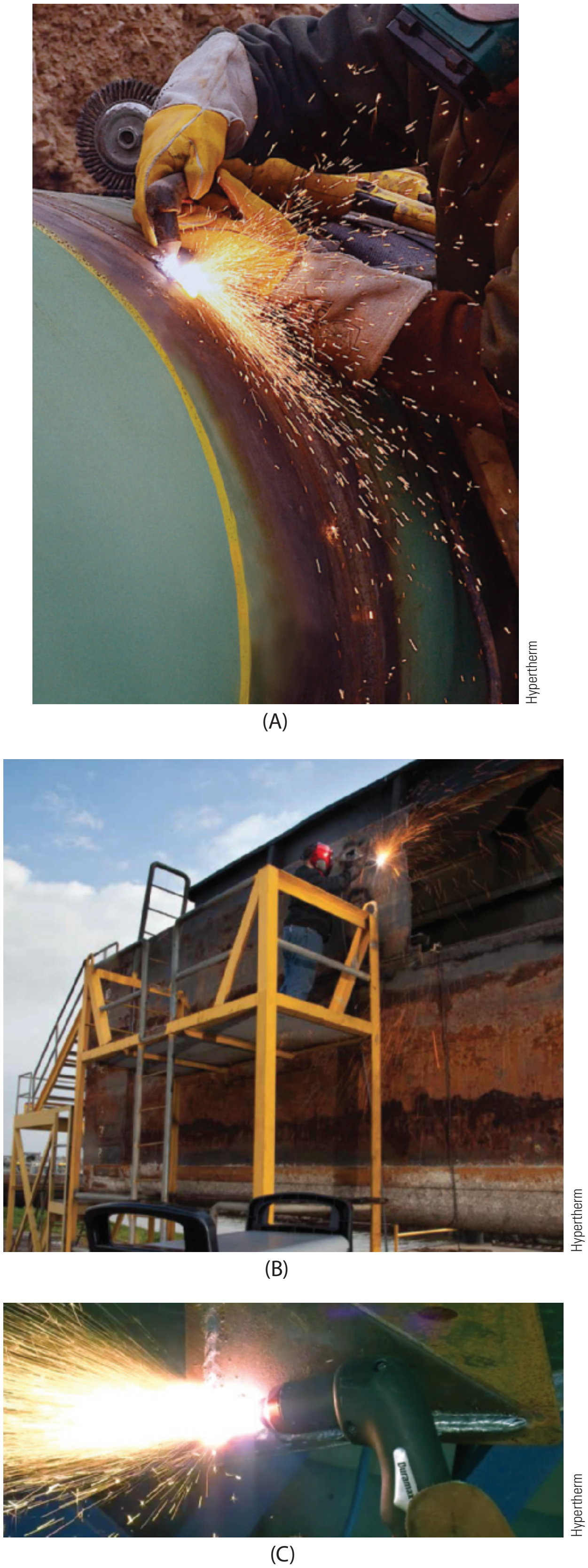


FIGURE 8-48 (A) Plasma gouging to remove a defective weld on a cross-country oil pipeline. (B) Plasma gouging being used to remove old rusty plating on a barge. (C) Plasma gouging being used to make a J-groove on the edge of a plate before it is welded.

FIGURE 8-49 Plasma removing of a weld.

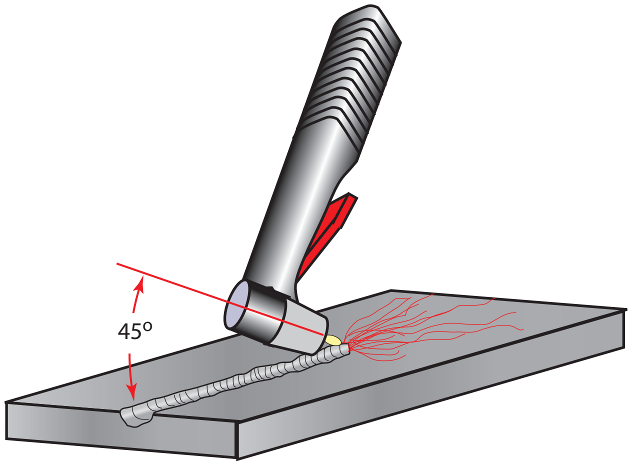


FIGURE 8-50 Plasma arc gouging a U-groove in a plate.

FIGURE 8-51 Plasma torch heat shield.

PRACTICE 8-5

U-Grooving of a Plate

Using a properly set up and adjusted PAC machine, proper safety protection, one or more pieces of mild steel, stainless steel, and aluminum 6 in. (152 mm) long and 1/4 in. (6 mm) or 1/2 in. (13 mm) thick, you will cut a U-groove down the length of the plate.

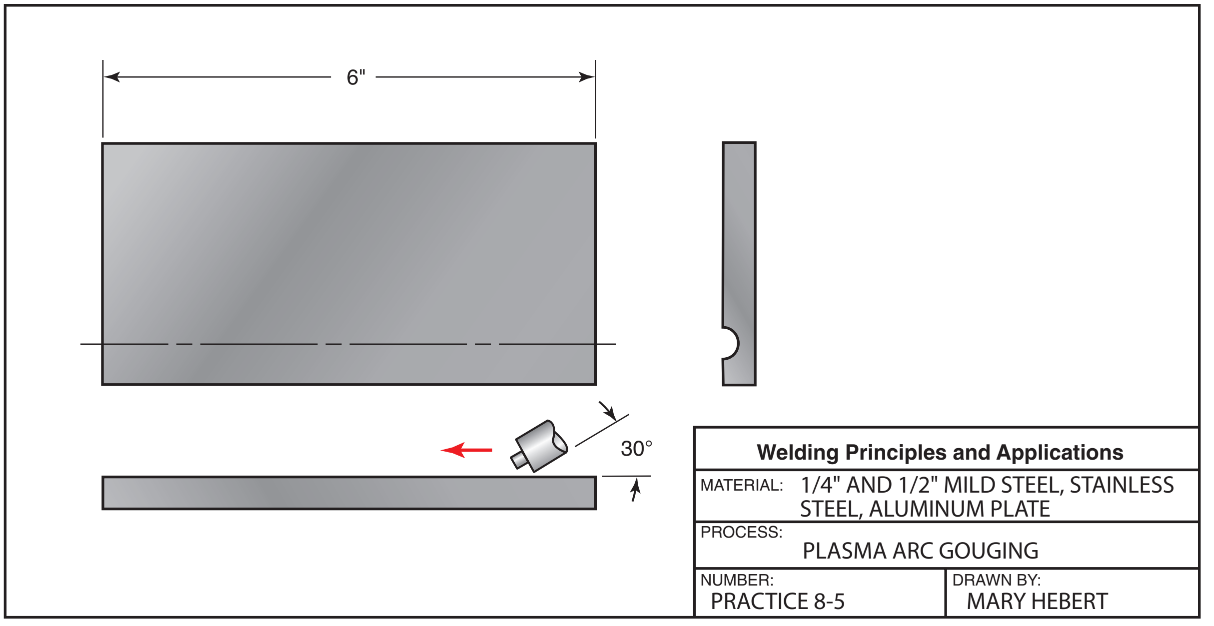


FIGURE 8-52 Plasma arc gouging.

- Starting at one end of the piece of metal, hold the torch as close as possible to a 45° angle, **Figure 8-52**.
- Lower your hood and establish a plasma cutting stream.
- Move the torch in a straight line down the plate toward the other end.
- If the width of the U-groove changes, speed up or slow down the travel rate to keep the groove the same width and depth for the entire length of the plate.

Repeat the gouging of the U-groove using all three types of metals until you can make consistently smooth grooves that are within ±3/32 in. (2.3 mm) of a straight 30° line and uniform in width and depth. Turn off the PAC equipment and clean your work area when you are finished cutting.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

CUTTING ROUND STOCK

Often it is necessary to PA cut a round piece of metal such as a pipe, shaft, rod, or bolt. Round pieces of metal can be a challenge to cut because the cut starts out much like a gouged groove and transitions to something like piercing a hole. In addition, it is important to keep the plasma stream straight and in line with the line that is being cut. The plasma torch will cut in the direction it is pointed, so if it is not straight, the cut may have a beveled edge.

PRACTICE 8-6

Cutting Round Stock

Using a properly set up and adjusted PAC machine, proper safety protection, and one or more pieces of pipe and bar stock, you will cut off strips 1/2 in. (13 mm) wide.

- Hold the torch so it is pointed parallel to the round piece and in line with the line to be cut, **Figure 8-53**.
- Lower your hood and pull the trigger to start the pilot arc and the cutting plasma stream.
- Using one of the piercing techniques to begin the cut.
- If the round stock is 1/2 in. (13 mm) or smaller, keep the torch pointed in the same direction and move the torch across the piece.
- If the round stock is 1/2 in. (13 mm) or thicker than the PAC torch can cut through easily, then you must move

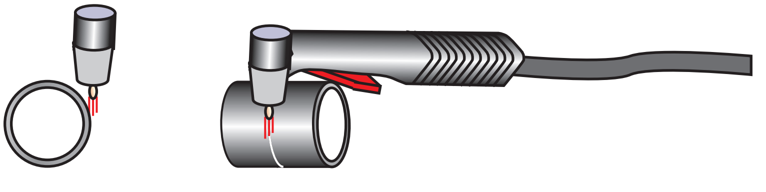


FIGURE 8-53 Cutting pipe with a plasma torch.

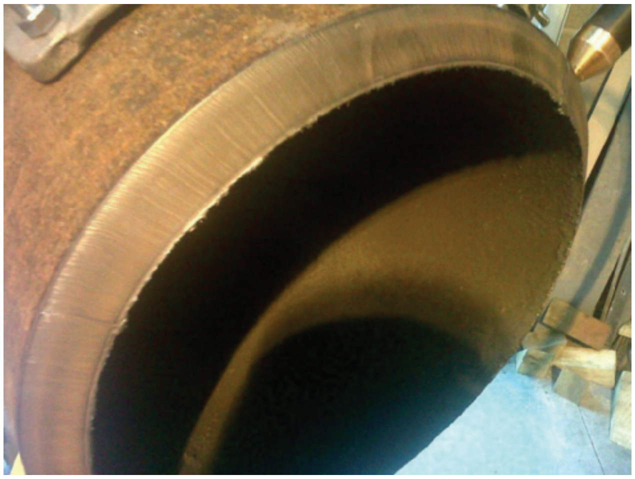
the torch back and forth to make the kerf wider to allow the cut to go all the way through the round stock.

Repeat the cut using both thicknesses of all three types of metals until you can make consistently smooth cuts that are within ±3/32 in. (2.3 mm) of a straight line and ±5° of being square. Turn off the PAC equipment and clean your work area when you are finished cutting.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

BEVELING PIPE

Pipe cutting machines can be manually operated, or they may have a drive motor, **Figure 8-54**. Set up the plasma cutting torch in the same way as you have for the manual cutting practices. When the cut begins, the torch must be moved at a constant speed. If the torch moves too slowly, then the sides of the kerf melt, making it wider. If the torch is moved too fast, then the cut may not be made all the way through the pipe's wall thickness.



Hypertherm

FIGURE 8-55 Smooth, uniform pipe bevel.

Hypertherm

(A)

Hypertherm

(B)

FIGURE 8-54 (A) Hand-cranked pipe beveling machine. (B) Motorized pipe beveling machine.

Watching the way the slag is blown out the back of the cut is the best way of judging the cutting speed. At the correct cutting speed the slag will be shot out in a stream, Figure 8-35A and B. There will be little or no slag hanging to the under edge of the bevel side of the cut, **Figure 8-55**, but there may be slag hanging on the scrap side of the cut.

Most cutting machines use spacers to position the machine's track ring so that it is centered on the pipe. Making certain that the correct spacers are used is important because if the track ring is off center, the bevel cut will not be square.

PRACTICE 8-7

Beveling Pipe

Using a properly set up and adjusted PAC machine, a manual or automatic pipe beveling machine, proper safety protection, and one or more pieces of pipe, you will cut a 45° bevel on the end of the pipe.

- Attach the pipe beveling machine to the pipe.
- Attach a machine plasma torch to the beveling machine carriage.
- Set the torch to a 45° angle.
- Run the carriage all the way around the pipe to check that it has freedom of movement and that the torch nozzle tip is traveling at the same height all the way around the pipe.
    - Clear any obstacles to the torch moving freely.
    - Change the beveling machine spacers if the tip height changes as the torch is moved all the way around the pipe.

- Using the running start technique of piercing the pipe, start the carriage moving at the same time the plasma stream is started.
- Watch the spark stream to determine that the cut is progressing at the correct speed.
  - Make any adjustments in speed to keep the spark stream flowing outward in a steady stream.
- If the beveled piece is to be used as a welding test coupon, you should hold it with a pair of pliers so that it does not drop to the floor. The hot pipe piece can be easily bent out of round if it hits the floor.

Repeat the cut until you can make consistently smooth beveled cuts. Turn off the PAC equipment and clean your work area when you are finished cutting.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

Summary

Plasma arc cutting is quickly becoming one of the most popularly used cutting processes in the welding industry. Developments and changes in the equipment and torch design have extended the effective cutting life for the consumable torch parts, which has reduced the cutting cost and improved cut quality significantly. This process was once found only in large shops that cut stainless steel and aluminum; however, today it is being used by almost every segment of the industry, including small shops and home hobbyists.

One of the most difficult parts of a plasma cutting process to be mastered by the beginning student is the high rate of cutting speed. Developing an eye and ear for the sights and sounds the process exhibits as a high-quality cut is being produced will be a significant aid in your skill development.

Early plasma arc cutting systems required either helium or argon gas to be used for the plasma and shielding gases. As the development of the process improved, it was possible to start the PAC torch using argon or helium and switch to less expensive nitrogen. The use of nitrogen as the plasma cutting gas greatly reduced the cost of operating a plasma system. Because of its operating expense, plasma cutting was limited to metals not easily cut using oxyfuel. Aluminum, stainless steel, and copper were the metals most often cut using plasma.

As the development of the process improved, less expensive gases and even dry compressed air could be used, and the torches and power supplies improved. By the early 1980s, the PAC process had advanced to a point where it was used for cutting all but the thicker sections of mild steel.

Review

1. List the types of metal that a plasma torch can be used to cut.
2. What two charged particles exist in a plasma?
3. What is the approximate temperature of a plasma stream?
4. To prevent a manual-type torch from damage, it is made of a special plastic that resists what?
5. How are high-power plasma torches cooled?
6. What is the name of the torch part made of copper with a very small tungsten embedded in the end?
7. What is the name of the material that resists oxidation at elevated temperatures so air can be used as a plasma gas?
8. What does the nozzle insulator provide to the plasma torch?
9. What are two other names that the shield is sometimes called?
10. How often should cables, control wiring, and hoses be inspected?
11. What may be on a coolant reservoir to indicate the coolant level?
12. Why is the cooling water switched on and off with the plasma?
13. Why must a filter dryer be used on the air supply to a plasma torch?
14. List the four common variations of the conventional plasma cutting process and describe the benefits of each.
15. Define standoff distance.
16. What two terms refer to the squareness of a cut?

17. What is the pilot arc?

18. List five factors that can affect the kerf width.

19. What factors affect the bevel angle left on the sides of all plasma cuts?

20. List five things that are affected by changes in the PAC gas(es).

21. What is dross?

22. List some advantages of using a water table.

23. Why are most hand PAC torches limited to 100 amperes or less?

24. List five special safety concerns for the PAC process.

25. Describe the three techniques for piercing a plate to start a cut: raising the torch, running start, and angling the torch.

26. Describe how to plasma gouge.

Chapter 9

Related Cutting Processes

OBJECTIVES

After completing this chapter, the student should be able to

- discuss the various cutting processes.
- give examples of the types of applications that might be best suited to specific cutting processes.
- list advantages and disadvantages of using the different cutting processes.
- explain the safety considerations of each of the different cutting processes.

KEY TERMS

abrasives

air carbon arc cutting (CAC-A)

carbon electrode

cutting gas assist

delamination

exothermic gases

gas laser

gouging

graphite

laser beam cuts (LBC)

laser beam drilling (LBD)

laser beam welds (LBW)

monochromatic

oxygen lance cutting

solid state lasers

synchronized waveform

washing

water jet cutting

weld removal

YAG laser

INTRODUCTION

The number of specialized cutting processes being developed and improved increases every year. To date there are a number of specialized cutting processes that have been perfected and are in use. The new cutting methods are being used by a much wider group than just the welding industry. These processes can be used to cut a wide variety of items, such as glass, plastic, printed circuit boards, cloth, and fiberglass insulation, and more items are being added almost daily. Material cutting and even hole drilling using a welding-related process have become common in the workplace.

Only a few of the more common cutting processes are covered in this chapter. These are the ones that a welder might be required to either be able to perform or have a working knowledge of.

LASER BEAM CUTTING (LBC) AND LASER BEAM DRILLING (LBD)

Lasers have developed from the first bright red spot generated by the ruby rod to a multibillion-dollar industry. The use of lasers has become very common today. We see their use in our world every day. They help speed our checking out at stores when they are used to read the uniform product code (UPC) on our purchases, **Figure 9-1**. Lasers are used by surveyors to measure distances and to see that a building under construction is level. Doctors can use lasers to make very precise cuts during the most delicate operations. They are even used to entertain us at shows and concerts.

This versatile tool has helped produce products that could not be produced without the laser's light. A laser can be used to drill holes (LBD) through the hardest materials, such as synthetic diamonds, tungsten carbide cutting tools, quartz, glass, or ceramics. Lasers are used for welding (LBW) materials that are too thin or too hard to be welded with other heat sources. They can be used to cut (LBC) materials that must be cut without overheating delicate parts that might be located just a few thousandths of an inch away.

The benefits and capacities of the laser have made it one of the most rapidly growing areas in manufacturing. This is a useful tool that will continue to be developed and improved for years to come.

Lasers

The term *laser* is an acronym for light amplification stimulation emission of radiation. A laser is a form of light that is **monochromatic**, a single-color wavelength that travels in parallel waves, **Figure 9-2**. This form of light is generated when certain types of materials are excited either by intense light or with an electric current. The atoms or molecules of the lasing material release their energy in the form of light. The laser light is produced as the atom or molecule slows down from a high energy state to a lower energy state, **Figure 9-3**. The laser light is then bounced back and forth between one fully reflective and one partially reflective surface at the ends of the lasing material. As the light is reflected, it begins to form a **synchronized waveform**. The light that passes through the partially reflective mirror is the laser light, and it is ready to do its job, **Figure 9-4**. The frequency of this vibration determines the color of the laser's light beam. Most lasers used for cutting, drilling, and welding produce a laser light beam in the infrared range.

When the laser beam exits the laser generator, it can be treated as any other type of light. It is possible to focus, reflect, absorb, or diffuse the light. By having the light waves traveling in such a uniform manner, they exhibit some specialized characteristics. The light beam tends to remain in a very tight column without spreading out, unlike ordinary light, **Figure 9-5**. This characteristic allows the laser beam to travel over some distance without significantly being affected by the distance it travels or the air it is traveling through.

Because the beam is not adversely affected by its travel, it can be used to carry information or transmit energy. When the laser wraps around a loaf of bread or a box of crackers, its image is so precise that the data in a uniform product code strip can accurately be received by the store's computer. The military uses lasers to aim weapons or identify targets so that they can be hit by missiles or bombs.

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FIGURE 9-1 Bar codes are read by lasers to input information into computers.

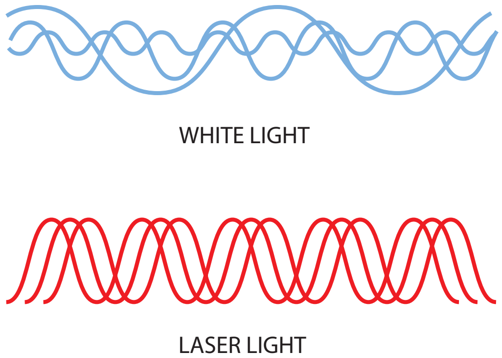


FIGURE 9-2 White light is made up of different frequencies (colors) of light waves. Laser light is made up of single-frequency light waves traveling parallel to each other.

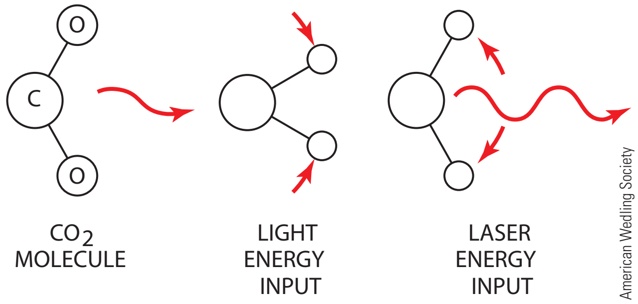


FIGURE 9-3 Energy is stored in a carbon dioxide (CO_2) molecule until the molecule cannot hold any more. The energy is released suddenly, like when a balloon pops. This quick release results in a burst of light energy.

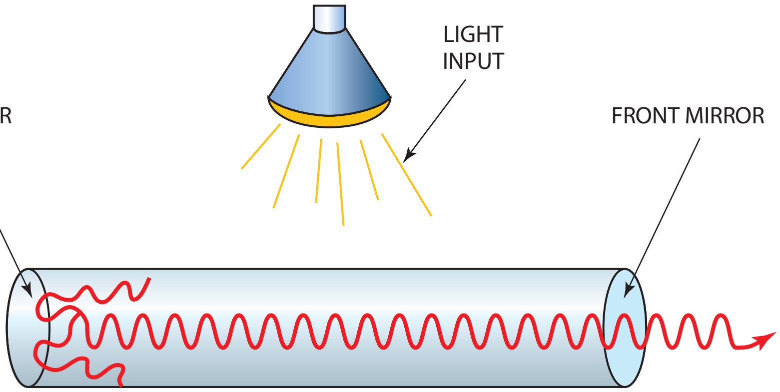


FIGURE 9-4 Light energy reflects back and forth between the end mirrors until it forms a parallel laser light beam.

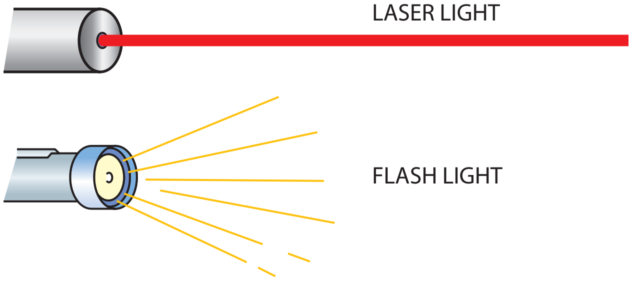


FIGURE 9-5 Laser light stays in a very tight column, unlike most other lights.

LASER TYPES

The early lasers all used a synthetic ruby rod as the material that produced the laser light. Today, a large number of materials can be used to produce the laser. These materials include common items such as glass and exotic items such as neodymium-doped, yttrium aluminum garnet (Nd:YAG), often referred to as a **YAG laser**, **Figure 9-6**.

Lasers can be divided into two major types: lasers using a solid material for the laser and lasers using a gas. Each of these two types is divided into two groups based on the method of operation: lasers that operate continuously and lasers that are pulsed.

Solid State Lasers

The first lasers were all **solid state lasers**. They used a ruby rod to produce the laser. Today, the most popular solid laser is the neodymium-doped, yttrium aluminum garnet (YAG). This is a synthetic crystal that, when exposed to the intense light from the flash tubes, can produce high quantities of laser energy. The high-powered solid lasers have a problem because the internal temperatures of the laser rod increase with operation time. These lasers are most often used with a low-power continuous or high-powered pulse. The solid state laser is capable of generating the highest-powered laser pulses.

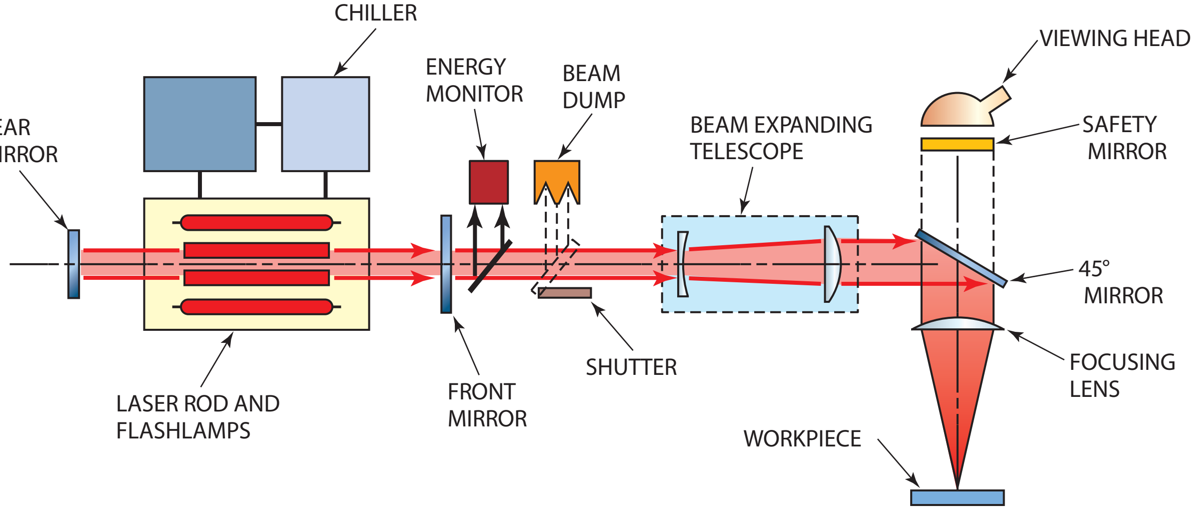


FIGURE 9-6 Schematic representation of the elements of a Nd: YAG laser.

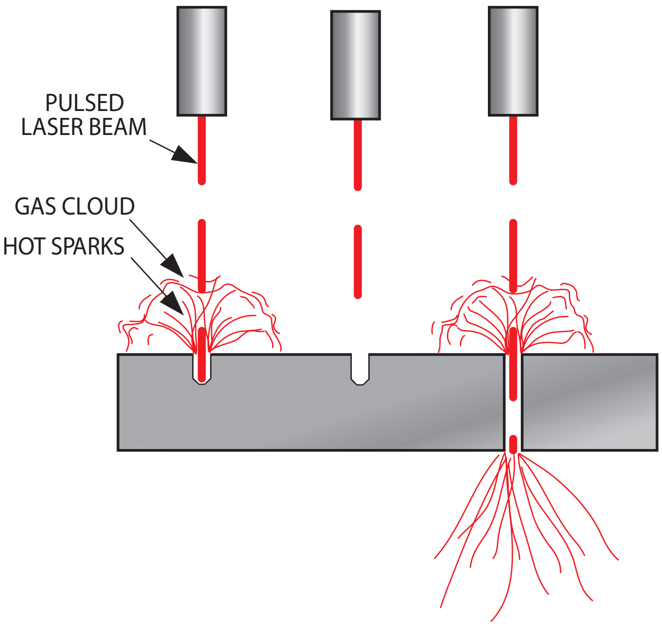


FIGURE 9-7 The gas cloud and hot sparks caused by the cutting laser beam dissipate between the pulses of the laser beam, which results in a better cut.

Gas Laser

The **gas laser** uses one or more gases for the laser. Popular gas-type lasers use nitrogen, helium, or carbon dioxide (CO_2), or mixtures of helium, nitrogen, and CO_2. Gas lasers either use a gas-charged cylinder where the gas is static or use a chamber that has a means of circulating the laser gas. The highest continuous power output-type lasers are the gas type with a blower to circulate the gas through a heat exchanger; they can be rapidly pulsed to improve their cutting capacity, **Figure 9-7**.

APPLICATIONS

Manufacturers use the laser to do everything from burning information on products as small and hard as diamonds to guiding machines to grind, cut, punch, drill, and cut to accuracies within a few thousandths of an inch. Fabricators are using lasers to cut, trim, weld, heat treat, clad, vapor deposit coatings, anneal, and shock harden metals. Lasers are often used to cut out thin sheet metal parts because lasers are more flexible and cost-effective than the commonly used punch presses. When punch presses are used, expensive punch and die tools have to be made first and, over time, as these tools wear out, replacements must be made.

Laser light beams can be focused into a very compact area. This allows the photo energy that the light possesses to be converted to heat energy as it strikes the surface of a material. The highly concentrated energy can cause the instantaneous melting or vaporization of the material being struck by the laser beam. The equipment used to produce **laser beam welds (LBW)**, **laser beam cuts (LBC)**, or **laser beam drilling (LBD)** is similar in design and operation. Most laser welding and cutting operations use a gas laser, and most drilling operations use a solid state laser.

The ability of a material's surface to absorb or reflect the laser light affects the laser's operating efficiency. All materials will reflect some of the laser's light, some more than others. The absorption rate will increase for any material once the laser beam begins to heat the surface. Once the threshold of the surface temperature is reached, the process will continue at a much higher level of efficiency.

Laser Beam Cutting

A laser weld and laser cut both bring the material to a molten state. In the welding process, the material is allowed to flow together and cool to form the weld metal. In the cutting process, a jet of gas is directed into the molten material to expel it through the bottom of the cut. Although the laser is used primarily to cut very thin materials, it can be used to cut up to 1 in. (2.5 cm) of carbon steel.

The **cutting gas assist** can be either a nonreactive gas or an exothermic. **Table 9-1** lists the various gases and the materials that they are used to cut. Nonreactive gases do not add any heat to the cutting process; they simply remove the molten material by blowing it out of the kerf. **Exothermic gases** react with the material being cut, like an oxyfuel cutting torch. The additional heat produced as the exothermic cutting gas reacts with the metal being cut helps blow the molten material out of the kerf.

Following are some advantages of laser cutting:

- Narrow heat-affected zone—Little or no heating of the surrounding material is observed. It is possible to make very close parallel cuts without damaging the strip that is cut out, **Figure 9-8**.
- No electrical conductivity required—The part being cut does not have to be electrically conductive, so materials like glass, quartz, and plastic can be cut. There is also no chance that a stray electrical charge

Assist Gases	Material
Air	Aluminum Plastic Wood Composites Alumina Glass Quartz
Oxygen	Carbon steel Stainless steel Copper
Nitrogen	Stainless steel Aluminum Nickel alloys
Argon	Titanium

TABLE 9-1 Various Cutting Assists Gases and the Materials They Cut

Larry Jeffus

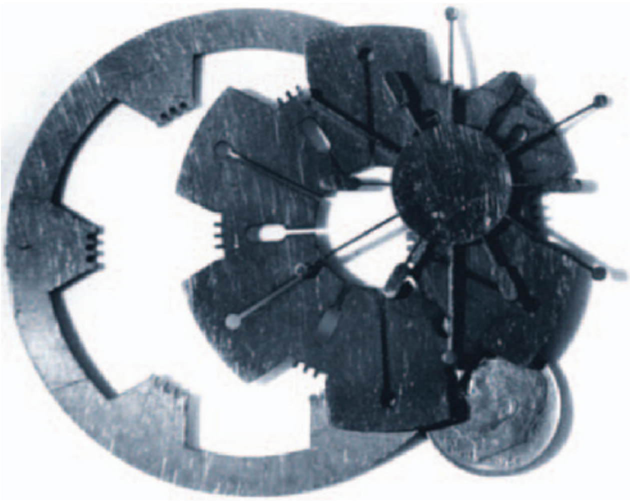
FIGURE 9-8 Detailed small part not much larger than a dime made with a laser.

might damage delicate computer chips while they are being cut using a laser.

- Noncontact—Nothing comes in contact with the part being cut except the laser beam. Small parts that may have finished surfaces or small surface details can be cut without the danger of disrupting or damaging the surface. It is also not necessary to hold the parts securely as it is when a cutting tool is used.
- Narrow kerf—The width of the kerf is very small, which allows the nesting of parts in close proximity to each other, which will reduce waste of expensive materials, **Figure 9-9**.
- Automation and robotics—The laser beam can be easily directed through a fiber optic cable to the working end of an automated machine or a robot.
- Top edge—The top edge will be smooth and square without being rounded.

Following are some limitations of laser cutting:

- Stacked materials can have significantly different melting temperatures.
- Component placement on fabrications can limit the beam's access for some cuts.



Larry Jeffus

FIGURE 9-9 Because of the narrow kerf, small, detailed parts can be nested one inside the other.

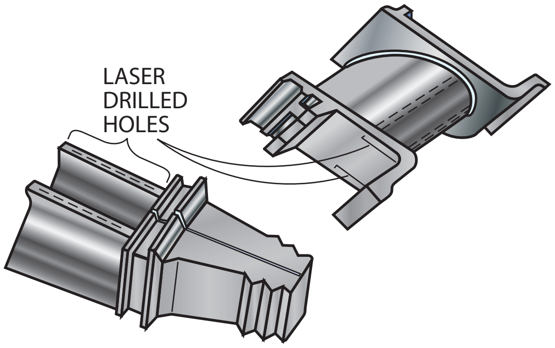


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FIGURE 9-10 Jet engine blades and a rotor component showing laser-drilled holes.

- Materials thicker than 0.40 in. can often be cut more efficiently with another process.

Laser Beam Drilling

The pulsed laser is the best choice for drilling operations. A very short burst of high laser energy is concentrated on a small spot. The intense heat vaporizes the small spot with enough force to thrust the material out, leaving a small crater. The repeated blasting to the pulsed laser results in the crater becoming increasingly deeper. This process continues until the hole is drilled through the part or to a desired depth, **Figure 9-10.**

A laser can be used to drill holes through the hardest materials, such as tungsten carbide cutting tools, quartz, glass, ceramics, or even synthetic diamonds. No other drilling process can match the precision, speed, or economy of the laser drill.

Lasers can drill up to 600 holes per minute through a 1/8-in. (3-mm) -thick steel plate, and holes as small as 0.0001 in. (0.0025 mm) in diameter can be drilled. The limitation on the hole's depth is the laser's focal length. Most holes are less than 1 in. (2.5 cm) in depth.

Laser Beam Welding

The laser beam can be used to melt the surface of the materials so they can flow together and cool to form the weld metal. Most laser beam welding is performed on thin materials. Following are some advantages of laser beam welding:

- The highly focused laser beam's heat allows it to make welds on very small thin parts.
- Welds can be made that are narrow and have deep penetration, **Figure 9-11**.
- The laser's high welding speeds produce very narrow heat-affected zones.
- The very fast localized heating results in little or no postweld distortion.
- There is no electric current that might damage sensitive electronic parts that are being welded on or nearby.

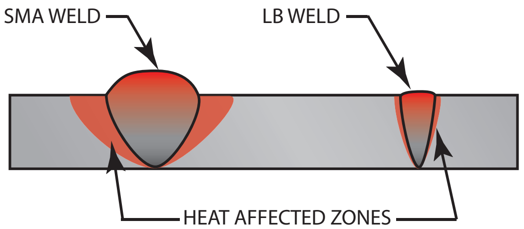

FIGURE 9-11 The smaller welds and heat-affected zone of laser beam welds reduce weld distortion.

HYBRID LASER PROCESS

The combining of a laser beam with a GMA welding gun or a GTA welding torch can provide the LBW process with a number of significant benefits.

Laser Beam Welding with Gas Metal Arc Welding

Combining LBW and GMAW results in a number of significant enhancements to welds that are not possible without their working together, **Figure 9-12A**.

- The edges of parts being LB welded normally must fit tightly together to allow the edges to flow together as they are melted.
  - The addition of filler metal from the GMA welding gun allows some small gaps to be filled and it adds weld reinforcement.
- LB welding melts the base metal to form the weld.
  - The addition of alloys in the GMA welding wire can help refine the grain structure of the finished weld to improve the welds properties such as strength, ductility, corrosion resistance, machinability, etc.
- The addition of low-cost arc heat from the GMA welding process can reduce the high-cost laser power requirement.
  - The laser significantly increases the GMA welding speed, heat-affected zone, distortion, and depth of penetration.

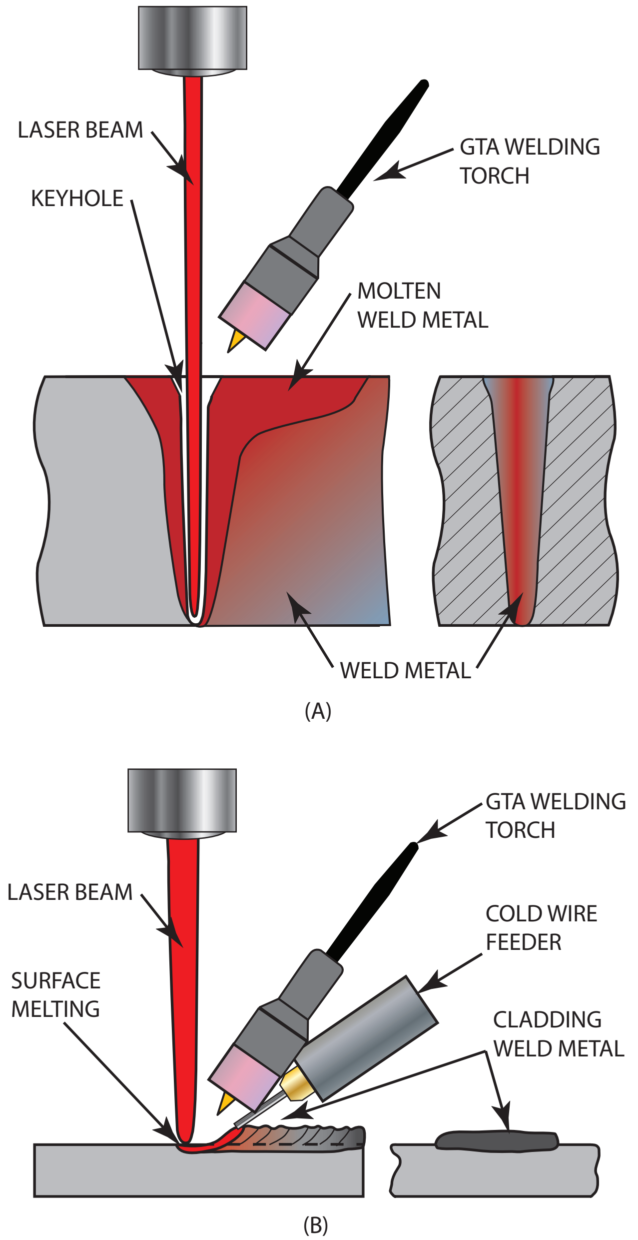

FIGURE 9-12 (A) Hybrid GTA welding. (B) Hot wire GTA cladding.

Laser Beam with Gas Metal Arc Welding Surfacing

Surface cladding can be performed by combining the laser beam with the addition of GMA welding filler metal. This combination will produce cladding that has excellent surface fusion with very little penetration, resulting in a minimum of base metal dilution into the cladding metal, **Figure 9-12B**.

Laser Beam Welding with Gas Tungsten Arc Welding

The combination of a laser beam with heat of the arc from a GTA welding torch provides both processes with some significant advantages. The GTAW process can be used with or without filler metal being added. However, the addition of filler metal greatly expands the range of benefits of this process. When a filler wire is automatically fed into the GTA welding arc it is referred to as Cold Wire Gas Tungsten Arc Welding.

- GTAW has less spatter than GMAW, so the Cold Wire GTAW with LBW has little to no spatter for postwelding cleanup.
- GTAW can be used to add lower-cost arc heat to the LBW process without having to add filler metal, which is an advantage for surface heat treatments.

- The arc heat for the GTAW process is independent of the cold wire feeding rate, so the welding heat input and filler metal feed can be controlled separately.

LASER EQUIPMENT

Most lasers range from 400 to 1500 watts in power. Some large machines have as much as 25 kW of power. Although the power of most lasers is relatively small when compared to other welding processes, it is the laser's ability to concentrate the power into a small area that makes it work so well. The power density of a cutting laser can be equal to 65 million watts per square inch.

Laser equipment is larger than most of the other welding or cutting power supplies. A typical unit will require approximately as much floor space as a large desk (approximately 10 sq ft.).

Recent advancements, increased competition, and a rapidly increasing market have helped lower the high cost of the equipment. But even with the current cost of equipment, laser cutting and drilling have one of the lowest average hourly operating costs. The high reliability and long life of the equipment have also helped reduce operating costs.

AIR CARBON ARC CUTTING (CAC-A)

The **air carbon arc cutting (CAC-A)** process was developed in the early 1940s and was originally named air arc cutting (AAC). Air carbon arc cutting was an improvement of the carbon arc process. The carbon arc process was used in the vertical and overhead positions and removed metal by melting a large enough spot so gravity would cause it to drip off the base plate. This process was slow and could not be accurately controlled. A recurring problem when removing rivet heads, as shown in **Figure 9-13**, was that some of the molten rivet head could weld itself to the base metal in any position other than overhead. It was found that by using a stream of air, the molten metal could be blown away. This greatly improved the speed, quality, and controllability of the process.

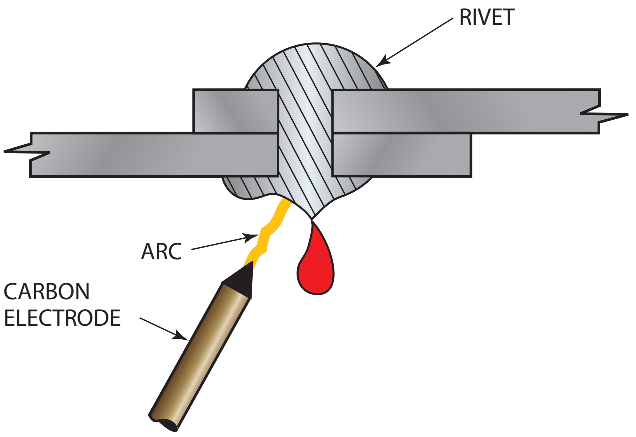

FIGURE 9-13 A carbon electrode was used to melt the head off rivets.

In the late 1940s, the first air carbon arc cutting torch was developed. Before this development the process required two welders, one to control the carbon arc and the other to guide the air stream. The new torch had both the carbon electrode holder and the air stream in the same unit. This basic design is still in use today, **Figure 9-14**.

Unlike the oxyfuel process, the air carbon arc cutting process does not require the base metal to be reactive with the cutting stream. Oxyfuel cutting can be performed only on metals that can be rapidly oxidized by the cutting stream of oxygen. The air stream in this process blows the molten metal away. This greatly increases the list of metals that can be cut, **Table 9-2**.

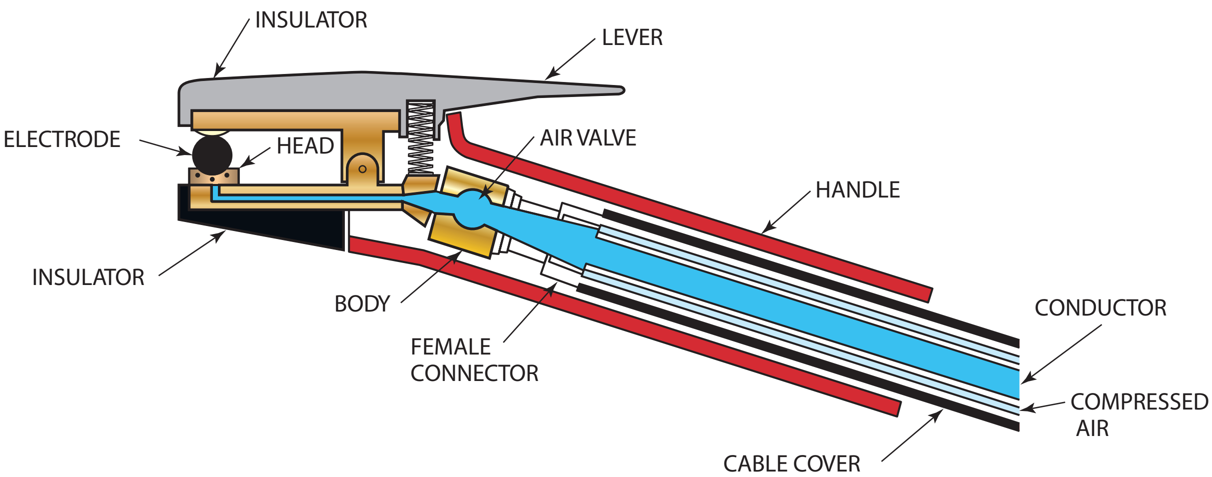

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FIGURE 9-14 Typical cross-section of an air carbon arc gouging torch.

Base Metals	Recommendations
Carbon steel and low alloy steel	Use DC electrodes with DCEP current. AC can be used but with a 50% loss in efficiency.
Stainless steel	Same as for carbon steel.
Cast iron, including malleable and ductile iron	Use of 13 mm or larger electrodes at the highest rated amperage is necessary. There are also special techniques that need to be used when gouging these metals. The push angle should be at least 70° and depth of cut should not exceed 13 mm per pass.
Copper alloys (copper content 60% and under)	Use DC electrodes with DCEN (electrode negative) at maximum amperage rating of the electrode.
Copper alloys (copper content over 60%, or size of workpiece is large	Use DC electrodes with DCEN at maximum amperage rating of the electrode or use AC electrodes with AC.
Aluminum bronze and aluminum nickel bronze (special naval propeller alloy)	Use DC electrodes with DCEN.
Nickel alloys (nickel content is over 80%)	Use AC electrodes with AC.
Nickel alloys (nickel content less than 80%)	Use DC electrodes with DCEP.
Magnesium alloys	Use DC electrodes with DCEP. Before welding, surface of groove should be wire brushed.
Aluminum	Use DC electrodes with DCEP. Wire brushing with stainless wire brushes is mandatory prior to welding. Electrode extension (length of electrode between electrode torch and workpiece) should not exceed 76 mm for good-quality work. DC electrodes with DCEN can also be used.
Titanium, zirconium, hafnium, and their alloys	Should not be cut or gouged in preparation for welding or remelting without subsequent mechanical removal of surface layer from cut surface.

Note: Where preheat is required for welding, similar preheat should be used for gouging.

TABLE 9-2 Recommended Procedures for Air Carbon Arc Cutting of Different Metals

THINK GREEN

Clean Up Any Possible Contamination

Some types of metals removed by the CAC-A cutting process can become groundwater or storm water contaminants if they are not cleaned up after outdoor cutting. It is a good idea to keep outdoor areas swept clean so rainwater does not wash heavy metals into the environment.

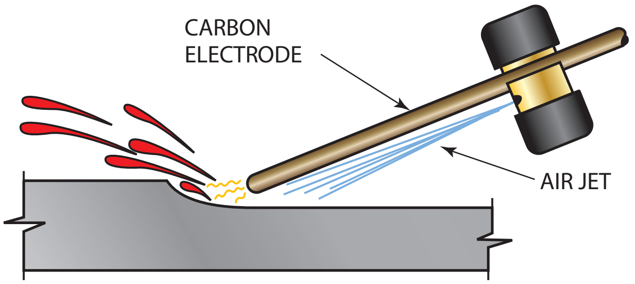

FIGURE 9-15 Air carbon arc gouging.

MANUAL TORCH DESIGN

The air carbon arc cutting torch is designed differently than the shielded metal arc electrode holder. Following are the major differences between an electrode holder and an air carbon arc torch:

- The lower electrode jaw has a series of air holes.
- The jaw has only one electrode-locating groove.
- The electrode jaw can pivot.
- There is an air valve on the torch lead.

By having only one electrode-locating groove in the jaw and pivoting the jaw, the air stream will always be aimed correctly. The air must be aimed just under and behind the electrode and always in the same direction, **Figure 9-15**. This ensures that the air stream will be directed at the spot where the electrode arcs to base the metal.

Torches are available in a number of amperage sizes. The larger torches have greater capacity but are less flexible to use on small parts.

The torch can be permanently attached to a welding cable and air hose, or it can be attached to welding power by gripping a tab at the end of the cable with the shielded metal arc electrode holder, **Figure 9-16**. The temporary attachment can be made easier if the air hose is equipped with a quick disconnect. A quick disconnect on the air hose will allow it to be used for other air tools such as grinders or chippers. Greater flexibility for a workstation can be achieved with this arrangement.

Electrodes

Air carbon arc cutting electrodes are available as copper-coated or plain (without a coating). The copper coating helps decrease the **carbon electrode** overheating by

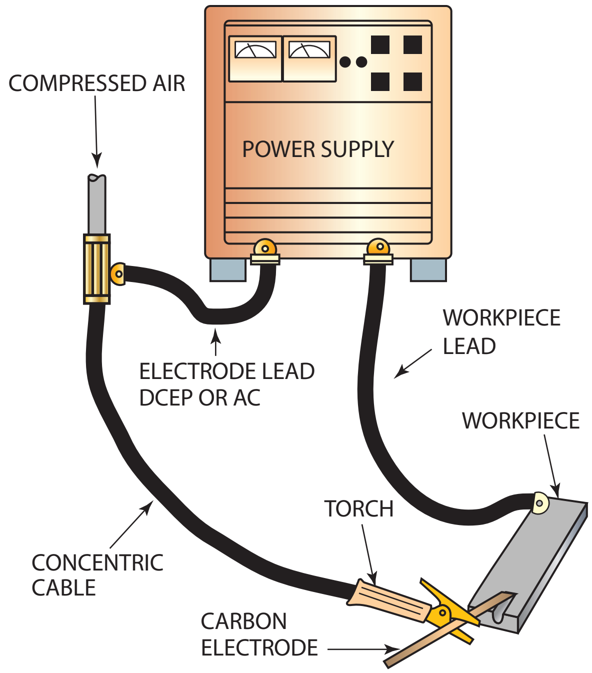

FIGURE 9-16 Air carbon arc gouging equipment setup.

increasing its ability to carry higher currents and improving the heat dissipation. The copper coating provides increased strength to reduce accidental breakage.

Electrodes can be round, flat, and semiround, **Figure 9-17**. The round electrodes are used for most **gouging** operations, and the flat electrodes are most often used to scarf off a surface. Round electrodes are also available in sizes ranging from 1/8 in. (3 mm) to 1 in. (25 mm) in diameter. Flat electrodes are available in 3/8 in. (10 mm) and 5/8 in. (16 mm) diameters.

Electrodes are available to be used on both direct-current electrode positive (DCEP) and alternating current. The DCEP electrodes are the most commonly used, and they are made of carbon in the form of **graphite**. The AC electrodes are less common; they have some elements added to the carbon to stabilize the arc, which is needed for the AC power.

To reduce waste, electrodes are made so that they can be joined together. The joint consists of a female tapered socket at the top end and a matching tang on the bottom end, **Figure 9-18**. The connection of the new electrode to the remaining setup will allow the stub to be consumed with little loss of electrode stock. This connecting of

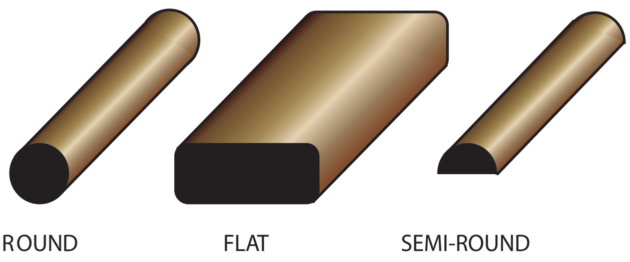

FIGURE 9-17 Cross-sections of carbon electrodes.

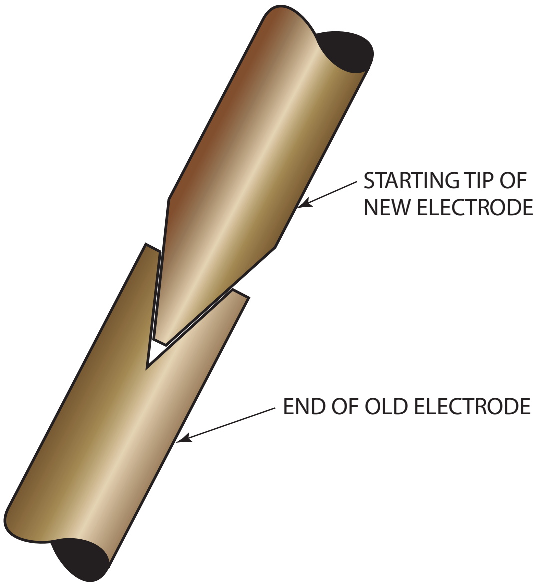

FIGURE 9-18 Air carbon arc electrode joint.

electrodes is required for most track-type air carbon arc cutting operations to allow for longer cuts.

The electrode should extend approximately 6 in. (152 mm) from the torch when starting a cut and, as the cut progresses, the electrode is consumed. Stop the cut and readjust the electrode when its end is approximately 3 in. (76 mm) from the electrode holder. This will reduce the damage to the torch caused by the intense heat of the operation.

POWER SOURCES

Most shielded metal arc welding power supplies can be used for air carbon arc cutting. The operating voltage required for air carbon arc cutting needs to be 35 volts or higher. This voltage is slightly higher than that required for most SMA welding, but most welders will meet this requirement. Check the manufacturer owner's manual to see if your welder is approved for air carbon arc cutting. If the voltage is lower than the minimum, the arc will tend to sputter out, and it will be difficult to make clean cuts.

Because most carbon arc cutting requires a high amperage setting, it may be necessary to stop some cuts so that the duty cycle of the welder is not exceeded. On large industrial welders this is not normally a problem.

AIR SUPPLY

Air supplied to the torch should be between 80 and 100 psi (550 and 690 kPa). The minimum pressure is approximately 40 psi (276 kPa). The correct air pressure will result in cuts that are clean, smooth, and uniform. The airflow rate is also important; it can range from 5 cu ft per min (3 L per min) to approximately 50 cu ft per min (24 L per min). If the air line is too small or if the compressor does not have the required capacity, then there will be a loss in air pressure at the torch tip. This line loss will result in a lower-than-required flow at the tip. The resulting cut will be less desirable in quality.

APPLICATION

Air carbon arc cutting can cut a variety of materials. It is a relatively low-cost way of cutting most metals, especially stainless steel, cast iron, aluminum, nickel alloys, and copper. Air carbon arc cutting is most often used for repair work. Few cutting processes can match the speed, quality, and cost-savings of this process for repair or rework.

Repair and Rework In repair or rework, the most difficult part is the removal of the old weld or cutting a groove so a new weld can be made. The air carbon arc can easily remove the worst welds even if they contain slag inclusions or other defects. For repairs, the arc can cut through thin layers of paint, oil, or rust and make a groove that needs little, if any, cleanup.

CAUTION

Never cut on any material that might produce fumes that would be hazardous to your health without taking proper safety precautions, including adequate ventilation and/or the wearing of a respirator.

Cast Iron The highly localized heat results in only slight heating of the surrounding metal. As a result, usually there is no need to preheat hardenable metals to prevent hardness zones. Cast iron is a metal that can be carbon arc gouged to prepare a crack for welding without causing further damage to the part by inputting excessive heat.

Weld Removal Air carbon arc cutting can be used to remove a welds on parts. The removal of welds can be accomplished with such success that often the part needs no postcut cleanup. The root of a weld can be back gouged so that a backing weld can be made ensuring 100% weld penetration, **Figure 9-19**.

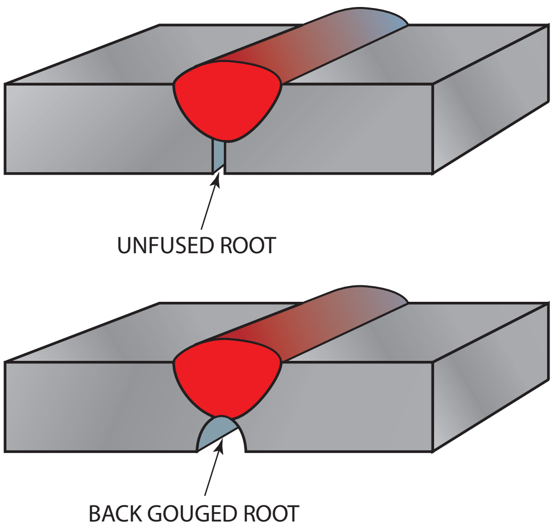

FIGURE 9-19 Back gouging the root of a weld made in thick metal can ensure that a weld with 100% joint fusion can be made.

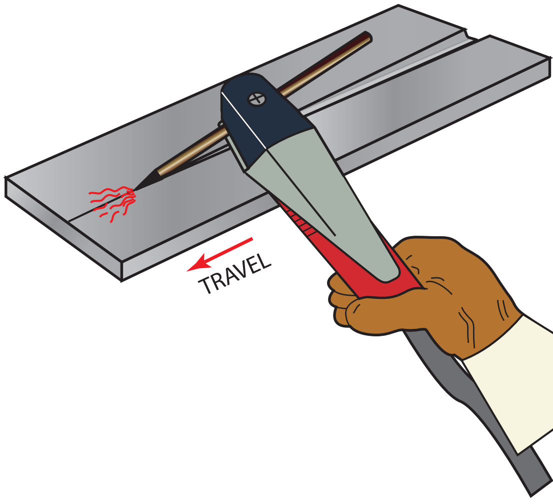

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FIGURE 9-20 Manual air carbon arc gouging operation in the flat position.

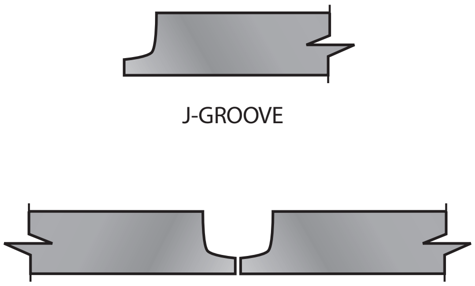


FIGURE 9-21 Air carbon arc gouging groove shapes.

Gouging Gouging is the most common application of the air carbon arc cutting processes. Arc gouging is the removal of a quantity of metal to form a groove or bevel, **Figure 9-20**. The groove produced along an edge of a plate is usually a J-groove. The groove produced along a joint between plates is usually a U-groove, **Figure 9-21**. Both grooves are used as a means to ensure that the weld applied to the joint will have the required penetration into the metal.

Washing **Washing** is the process sometimes used to remove large areas of metal so that hard surfacing can be applied, **Figure 9-22**. Washing can be used to remove large areas that contain defects, to reduce the transitional stresses of unequal-thickness plates, or to allow space for the capping of a surface with a wear-resistant material.

SAFETY

In addition to the safety requirements of shielded metal arc, air carbon arc requires several special precautions, such as the following:

- Sparks—The quantity and volume of sparks and molten metal spatter generated during this process are a major safety hazard. Extra precautions must be

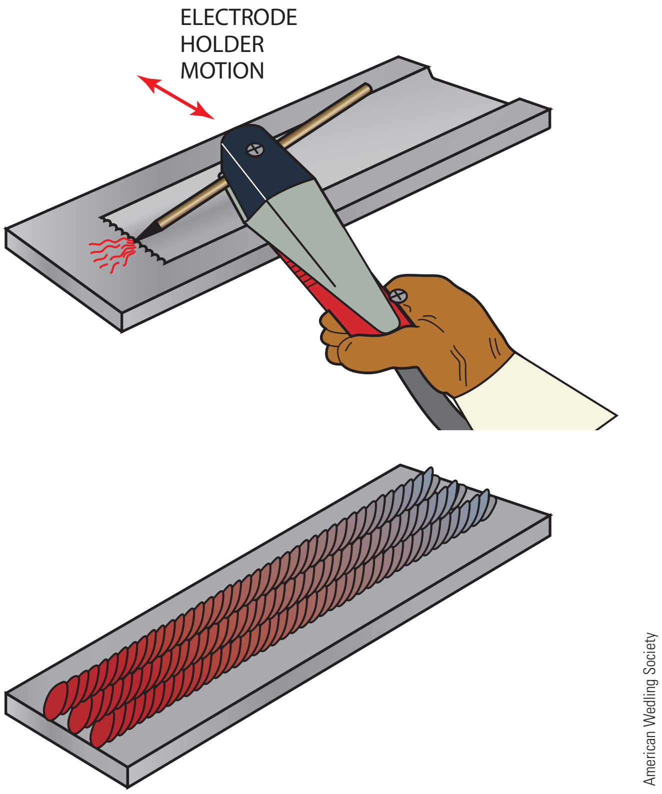


FIGURE 9-22 Hardsurfacing weld applied in the carbon-arc-cut groove.

taken to ensure that other workers, equipment, materials, or property in the area will not be affected by the spark stream. A piece of metal may be placed in line with the spark stream to stop the sparks or to reflect the sparks downward.

- Noise—This process produces a high level of sound. The sound level is high enough to cause hearing damage if proper ear protection is not used.
- Light—The arc light produced is the same as that produced by the shielded metal arc welding process. But because the arc has no smoke to defuse the light and the amperages are usually much higher, the chances of receiving arc burns are much higher. Additional protection should be worn, such as thicker clothing, a leather jacket, and leather aprons.
- Eyes—Because of the intense arc light, a darker welding filter lens for the helmet should be used.
- Fumes—The combination of the air and the metal being removed results in a high volume of fumes. Special consideration must be made for the removal of these fumes from the work area. Before installing a ventilation system, check with local, state, and federal laws. Some of the fumes may have to be filtered before they can be released into the atmosphere.
- Surface contamination—Often this process is used to prepare damaged parts so that they can be repaired. If the used parts have paint, oils, or other contaminants that might generate hazardous fumes, then they must be removed in an acceptable manner before any cutting begins.
- Equipment—Check the manufacturer's owner's manual for specific safety information concerning the power supply and the torch before you start any work with each piece of equipment for the first time.

THINK GREEN

Control Sound Pollution

CAC-A can produce high sound levels. Many communities have noise ordinances that define noise as a sound that is unwanted or annoying, and they set limits on sound levels. Sound barriers can be used to block the noise from CAC-A that adversely affects neighboring businesses or homes.

U-GROOVES

U-grooving is used to remove defective welds and to prepare a thick metal joint so that a full penetration weld can be made. Often the easiest way to prepare a joint for a full penetration weld is to use one of the thermal processes and cut a V-groove or bevel along the edge. However, sometimes parts must be fitted and assembled to ensure everything fits as designed before a groove can be cut. In these cases, a U-groove can be easily cut along the assembled edges of the joint.

PRACTICE 9-1

Air Carbon Arc Straight U-Groove in the Flat Position

Using an air carbon arc cutting torch and welding power supply that have been safely set up in accordance with the manufacturer's specific instructions in the owner's manual and wearing safety glasses, welding helmet, gloves, and any other required personal protection clothing, you will make a 6-in. (152 mm) -long straight U-groove gouge in a carbon steel plate.

1. Adjust the air pressure to approximately 80 psi.
2. Set the amperage within the range for the diameter electrode you are using by referring to the box the electrodes came in.
3. Check to see that the stream of sparks will not start a fire or cause any damage to anyone or anything in the area.
4. Make sure the area is safe, and turn on the welder.
5. Using a good, dry, leather glove to avoid electrical shock, insert the electrode in the torch jaws so that approximately 6 in. is extending outward. Be

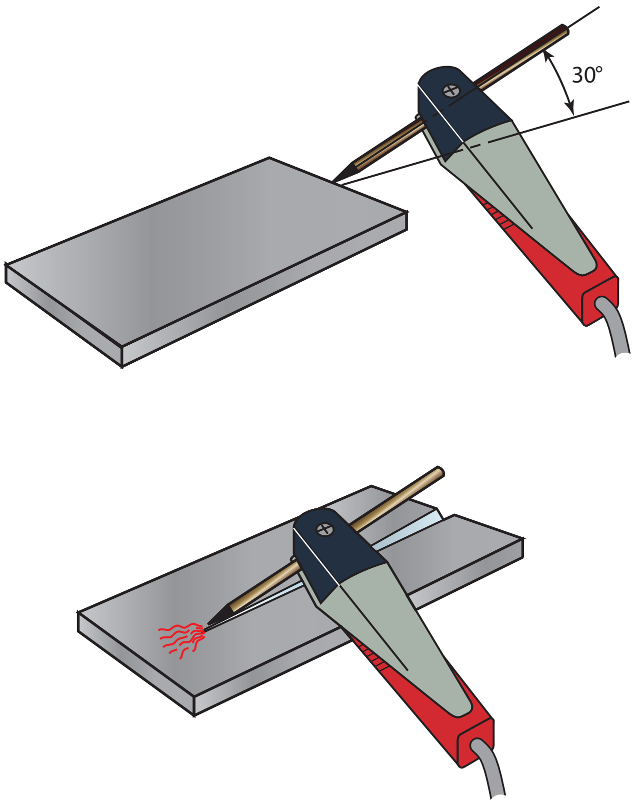


FIGURE 9-23 Air carbon arc U-groove gouging.

sure not to touch the electrode to any metal parts, because it may short out.

6. Turn on the air at the torch head.
7. Lower your arc welding helmet.
8. Slowly bring the electrode down at an approximately 30° angle so it will make contact with the plate near the starting edge, **Figure 9-23**. Be prepared for a loud, sharp sound when the arc starts.
9. Once the arc is struck, move the electrode in a straight line down the plate toward the other end. Keep the speed and angle of the torch constant.
10. When you reach the other end, lift the torch so the arc will stop.
11. Raise your helmet and stop the air.
12. Remove the remaining electrode from the torch so it will not accidentally touch anything.

When the metal is cool, chip or brush any slag or dross off of the plate. This material should remove easily. The groove must be within ±1/8 in. (3 mm) of being straight and within ±3/32 in. (2.4 mm) of uniformity in width and depth. Repeat this cut until it can be made within these tolerances. Turn off the CAC equipment and clean your work area when you are finished cutting.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 9-2

Air Carbon Arc Edge J-Groove in the Flat Position

Using the same equipment, adjustments, setup, and materials and process as described in Practice 9-1, you are going to make a J-groove along the edge of the plate.

1. Slowly bring the electrode down at an approximately 30° angle so it will make contact with the plate near the starting edge, **Figure 9-24**.
2. Once the arc is struck, move the electrode in a straight line down the edge of the plate toward the other end. Keep the speed and angle of the torch constant.
3. When you reach the other end, lift the torch so the arc will stop.
4. Raise your helmet and stop the air.
5. Remove the remaining electrode from the torch so it will not accidentally touch anything.

When the metal is cool, chip or brush any slag or dross off of the plate. This material should remove easily. The groove must be within ±1/8 in. (3 mm) of being straight and within ±3/32 in. (2.4 mm) of uniformity in width and depth. Repeat this cut until it can be made within these tolerances. Turn off the CAC equipment and clean your work area when you are finished cutting.

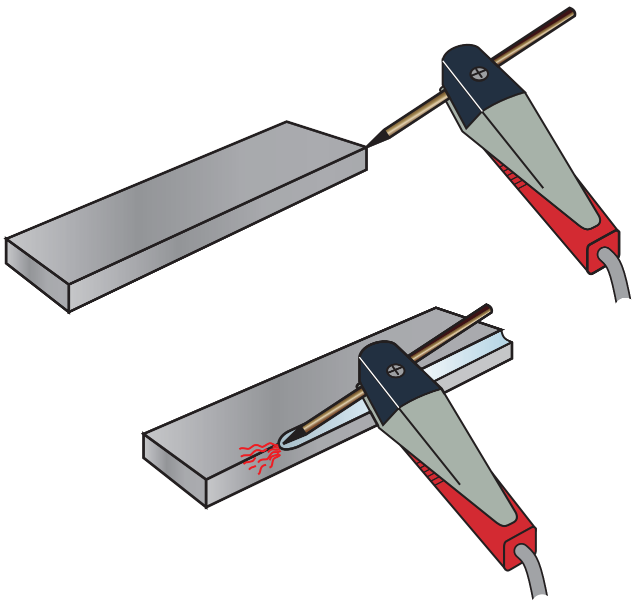


FIGURE 9-24 Air carbon arc J-groove gouging.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 9-3

Air Carbon Arc Back Gouging in the Flat Position

Using the same equipment, adjustments, setup, and materials process as described in Practice 9-1, you are going to make a U-groove along the root face of a weld joint on a plate, **Figure 9-25**.

Follow the same starting procedure as you did in Practice 9-1.

1. Start the arc at the joint between the two plates.
2. Once the arc is struck, move the electrode in a straight line down the edge of the plate toward the other end. Watch the bottom of the cut to see that it is deep enough. If there is a line along the bottom of the groove, then it needs to be deeper. Once the groove depth is determined, keep the speed and angle of the torch constant.
3. When you reach the other end, break the arc off.
4. Raise your helmet and stop the air.
5. Remove the remaining electrode from the torch so it will not accidentally touch anything.

When the metal is cool, chip or brush any slag or dross off of the plate. This material should remove easily. The groove must be within ±1/8 in. (3 mm) of being straight, but it may vary in depth so that all of the unfused root of the weld has been removed. Repeat this cut until it can be made within these tolerances. Turn off the CAC equipment and clean your work area when you are finished cutting.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 9-4

Air Carbon Arc Weld Removal in the Flat Position

Using the same equipment, adjustments, setup, and materials as described in Practice 9-1, you are going to make a U-groove to remove a weld from a plate, **Figure 9-26**.

Follow the same starting procedure as you did in Practice 9-1.

1. Start the arc on the weld.
2. Once the arc is struck, move the electrode in a straight line down the weld toward the other end. Watch the bottom of the cut to see that it is deep enough. If there is not a line along the bottom of the groove, then it needs to be deeper. Once the groove depth is determined, keep the speed and angle of the torch constant.
3. When you reach the other end, break the arc off.
4. Raise your helmet and stop the air.
5. Remove the remaining electrode from the torch so it will not accidentally touch anything.

When the metal is cool, chip or brush any slag or dross off of the plate. This material should remove easily. The groove must be within ±1/8 in. (3 mm) of being straight, but it may vary in depth so that all of the weld metal has been removed. Repeat this cut until it can be made within these tolerances. Turn off the CAC equipment and clean your work area when you are finished cutting.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

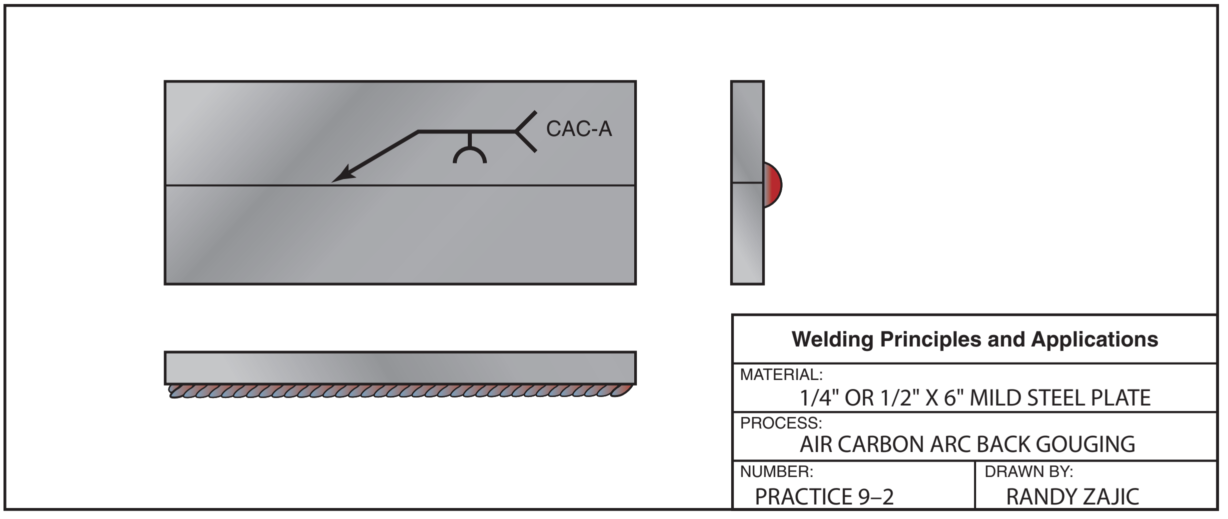


FIGURE 9-25 Air carbon arc back gouging.

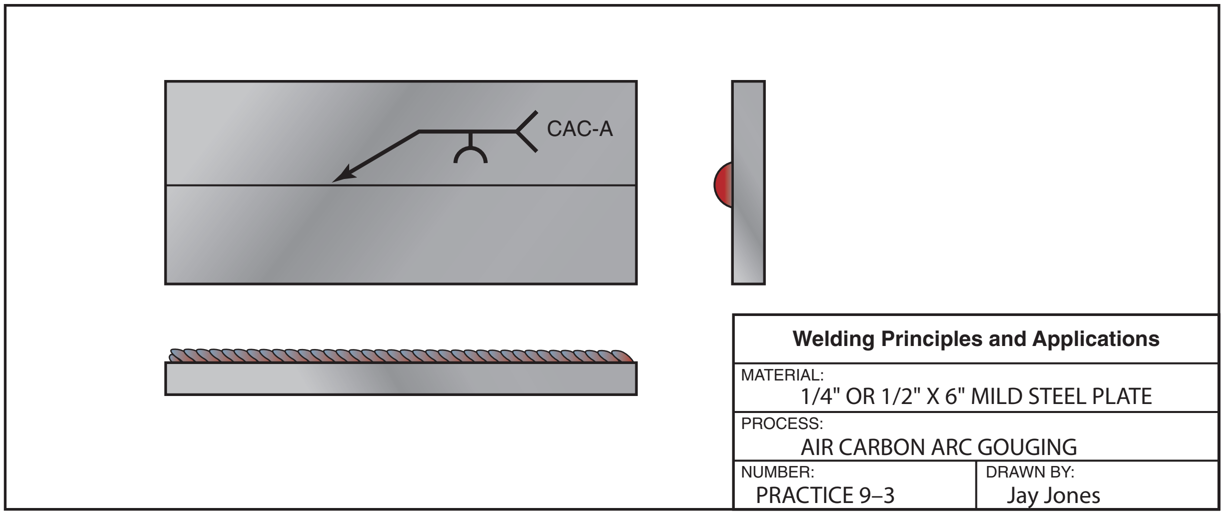


FIGURE 9-26 Air carbon arc weld gouging.

OXYGEN LANCE CUTTING

The **oxygen lance cutting** process uses a consumable alloy tube, **Figure 9-27.** The tip of the tube is heated to its kindling temperature. A high-pressure oxygen flow is started through the lance. The oxygen reacts with the hot lance tip, releasing sufficient heat to sustain the reaction, **Figure 9-28**.

The rod tip is heated up to a red-hot temperature using an oxyfuel torch or electric resistance. Once the oxygen stream is started, it reacts with the lance material, which results in the creation of both a high temperature and heat-releasing reaction.

The intense reaction of the lance allows it to be used to cut through a variety of materials. The hot metal leaving the lance tip has not completed its exothermic reaction. As this reactive mass impacts the surface of the material being cut, it releases a large quantity of energy into that surface. Thermal conductivity between the molten metal and

FIGURE 9-27 Oxygen lance rods may be rolled out of flat strips of special alloys to form a tube.

FIGURE 9-28 Arcair® SLICE® portable cutting system that uses sparks created between the striker and tube to ignite the oxygen lance rod for cutting.

the base material is a very efficient method of heat transfer. This, along with the continued burning of the lance material on the surface, causes the base material to become molten.

Once the base material is molten, it may react with the burning lance material, forming fumes or slag, which is then blown from the cut. Any molten material not becoming reactive is carried out of the cut with the slag or blown out with the oxygen stream.

The addition of steel rods or other metals to the center of the oxygen lance tube increases their productivity. The improved lances last longer and cut faster.

APPLICATIONS

The oxygen lance's unique method of cutting allows it to be used to cut material not normally cut using a thermal process. Films have portrayed the oxygen lance as a tool used by thieves to cut into safes. In reality, this would result in the valuables in the safe being destroyed. The oxygen lances can be used to cut reinforced concrete.

Fire and rescue personal can use it to cut heavy steel beams, concrete, or other material that may need to be quickly removed during a rescue. It allows the quick removal of thick sections of the building without the dangerous vibration caused by most conventional methods. The oxygen lance saved thousands of hours and countless lives in Mexico City following the devastation from the city's worst earthquake. Oxygen lances were used to cut large sections of concrete that fell from buildings into pieces of manageable sizes. Local and national news agencies showed building rubble being cut away by rescue workers using the oxygen lance.

The oxygen lance is also used to cut thick sections of cast iron, aluminum, and steel. Often in the production of these metals, thick sections must be cut. Occasionally, equipment failure will stop metal production. If the metal in production is allowed to cool, then it may need to be cut in sections so it can be removed from the machine. The oxygen lance's process is very effective in this type of work.

SAFETY

It is important to follow all safety procedures when using this process. Manufacturers list specific safety precautions for the oxygen lances they produce. Read and follow those instructions carefully. The major safety concerns are as follows:

- Fumes—The large quantity of fumes generated is often a health hazard. An approved ventilation system must be provided if this work is to be done in a building or any other enclosed area.
- Heat—This operation produces both high levels of radiant heat and plumes of molten sparks and slag. The operators must wear special heat-resistant clothing.
- Noise—Sound is produced well above safety levels. Ear protection must be worn by anyone in the area.

WATER JET CUTTING

Water jet cutting is not a thermal cutting process. This method of cutting does not put any heat into the material being cut. The cut is accomplished by the rapid erosion of the material by a high-pressure jet of water, **Figure 9-29**. An abrasive powder may be added to the stream of water. **Abrasives** are added when hard materials such as metals are being cut.

The lack of heat input to the material being cut makes this process unique. Materials that heat might distort, make harder, or cause to delaminate are ideally suited to this process. The lack of heat distortion allows thin material to be cut with the edge quality of a laser cut and as distortion-free as a shear cut. **Delamination** is not a problem when cutting composite or laminated materials, such as carbon fibers, resins, or computer circuit boards, **Figure 9-30**.

APPLICATIONS

The kerf width does not tend to change unless too high of a travel speed is being used. This results in a square, smooth finish on the cut surface. Postcut cleanup of the parts is totally eliminated for most materials, and only slight work is needed on a few others, **Figure 9-31**. The quality of the cut surface can be controlled so that even parts for the aerospace industry can often be assembled as cut.

The addition of an abrasive powder can speed up the cutting, allow harder materials to be cut, and improve the surface finish of a cut. The powder most often used is garnet. It is also commonly used as an abrasive on sandpaper. If an abrasive is used, the small water jet orifice will wear out faster.

Materials that often gum up a cutting blade, such as plexiglass, ABS plastic, and rubber, can be cut easily. There is nothing for the material to adhere to that would disrupt the cut. The lack of heat also reduces the tendency of the material's cut surface to become galled.

Most water jet cutting is performed by some automated or robotic system. There are a few band-saw-type, hand-fed cutting machines that are used for single cuts or when limited production is required.

ARC CUTTING ELECTRODES

Arc cutting electrodes do not require any special equipment other than a standard SMA welding machine, and they fit into the standard electrode holder. Because the arc cutting electrodes work with any standard arc welder, this makes them the ideal choice for many cutting jobs. For example, if only an occasional cut is needed, the expense of having either an OFC or a PAC piece of equipment cannot be justified. Many types of arc cutting electrodes can make clean cuts, although they may not make as square, smooth, and clean of a cut as many other cutting processes. But they are much easier and faster to use than a metal saw for cutting or drilling a hole in thick metal.

Arc cutting electrodes are available for cutting steel, stainless steel, cast iron, aluminum, copper alloys, and many other metals. Steel up to 1 1/2 in. (37 mm) thick can

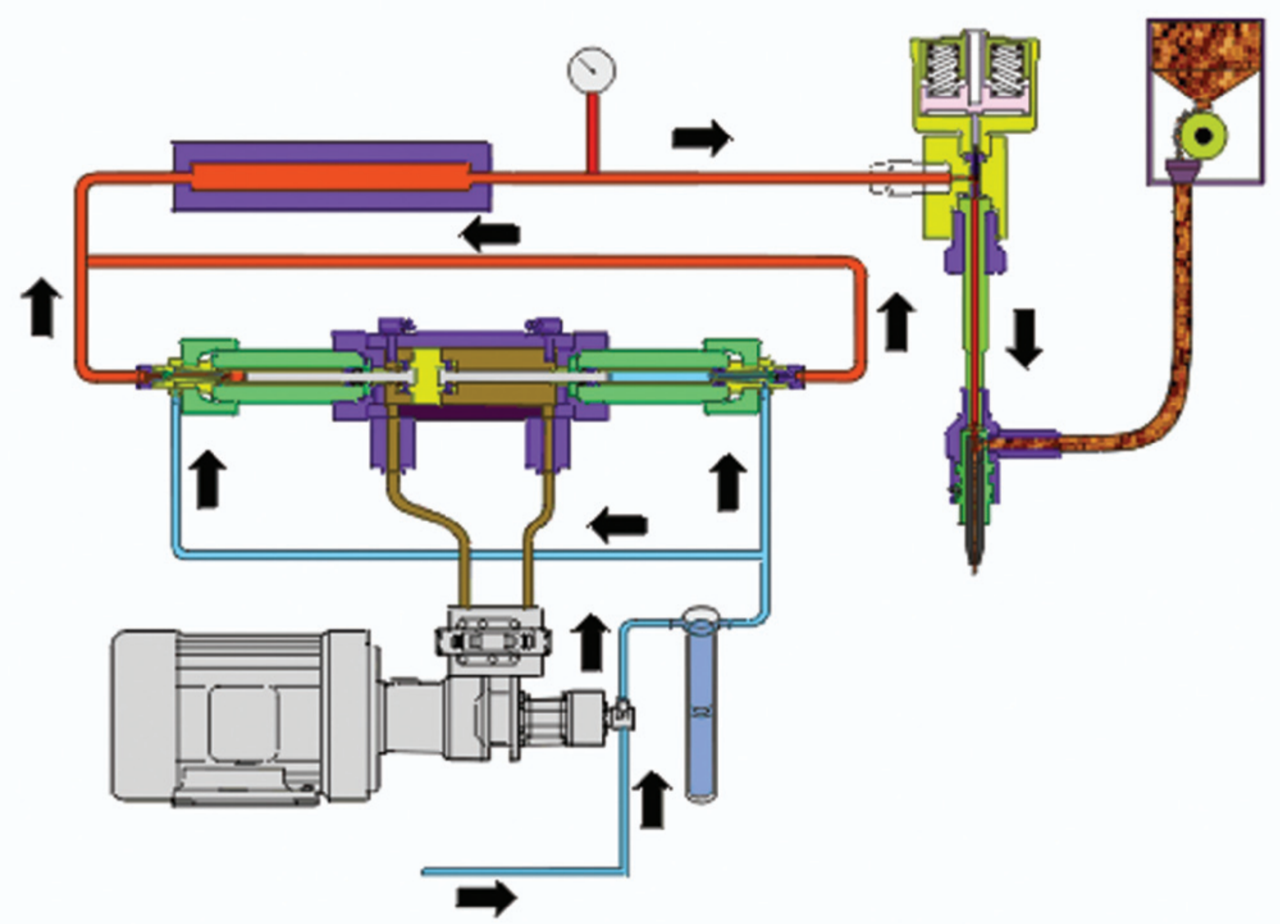


FIGURE 9-29 Basic diagram illustrating the elements of the water jet cutting system.

FIGURE 9-30 Water jet cutting is very fast, clean, and free from heat distortion.

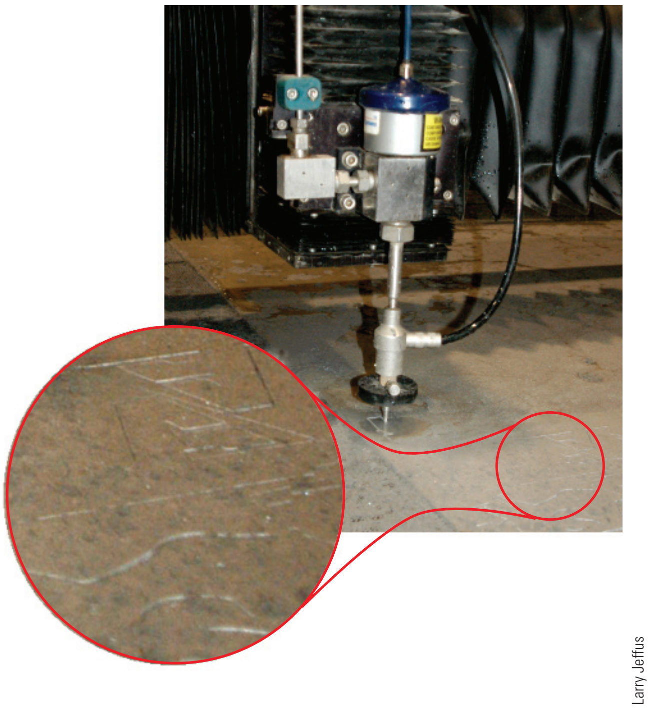


FIGURE 9-31 Notice how narrow and clean this cut is.

be cut using this process. Some arc cutting electrodes are available for cutting underwater, where using an acetylene torch might be difficult or impossible.

Arc cutting electrodes differ from standard arc welding electrodes in that they burn back inside the outer flux covering, creating a small cavity, **Figure 9-32**. The heat of the arc causes the metal core and inner layer of flux to vaporize and rapidly expand. The small cavity acts like a small combustion chamber, and the hot vaporized material is blasted out like a small jet engine. Combined with the heat of the arc and the jetting action, the metal is cut.

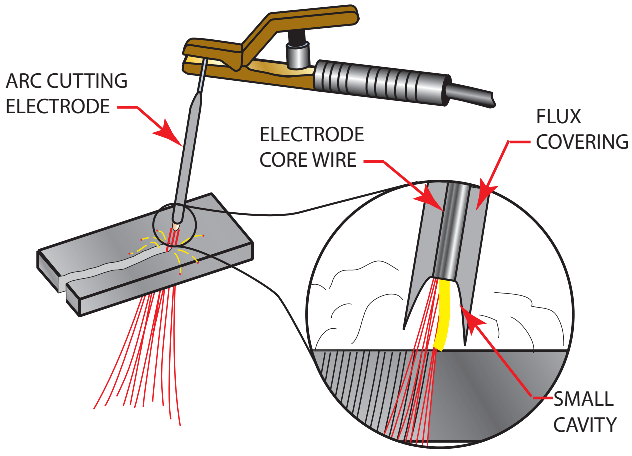


FIGURE 9-32 The small cavity at the end of the electrode creates enough jetting action to blow the molten metal formed by the arc away to form a cut.

APPLICATIONS

This cutting process is ideal any time that it is not practical or cost-effective to bring along an oxygen acetylene cutting set and cylinders or a plasma cutting machine. Arc cutting electrodes can be used to cut metal, pierce holes, or to gouge a groove for welding or gouge out a defective weld.

Summary

The welding field's ability to provide industry with a wide variety of cutting processes has increased productivity for a many different industries. An example of this diversity is the use of a laser beam to cut apart computer chips in the electronics field. Without these cutting processes, industry would have to rely on the much slower and more expensive mechanical or abrasive cutting process. There are no mechanical or abrasive cutting processes that can compete with the speed of these new cutting processes and none that can compete with their versatility.

Somewhat less attractive, but nonetheless efficient, processes such as carbon arc gouging and oxygen lance cutting fulfill specific industrial applications, such as salvage or scrap work. Few cutting processes can rival the metal-removing capacity of the air carbon arc or oxygen lance processes. In addition, the low cost of the equipment and the flexibility and application of these processes have lent themselves very successfully to the salvage and scrap industry. Air carbon arc gouging is extensively used for **weld removal** and repair work. A skilled technician can produce a groove that requires little or no postcut cleanup prior to rewelding.

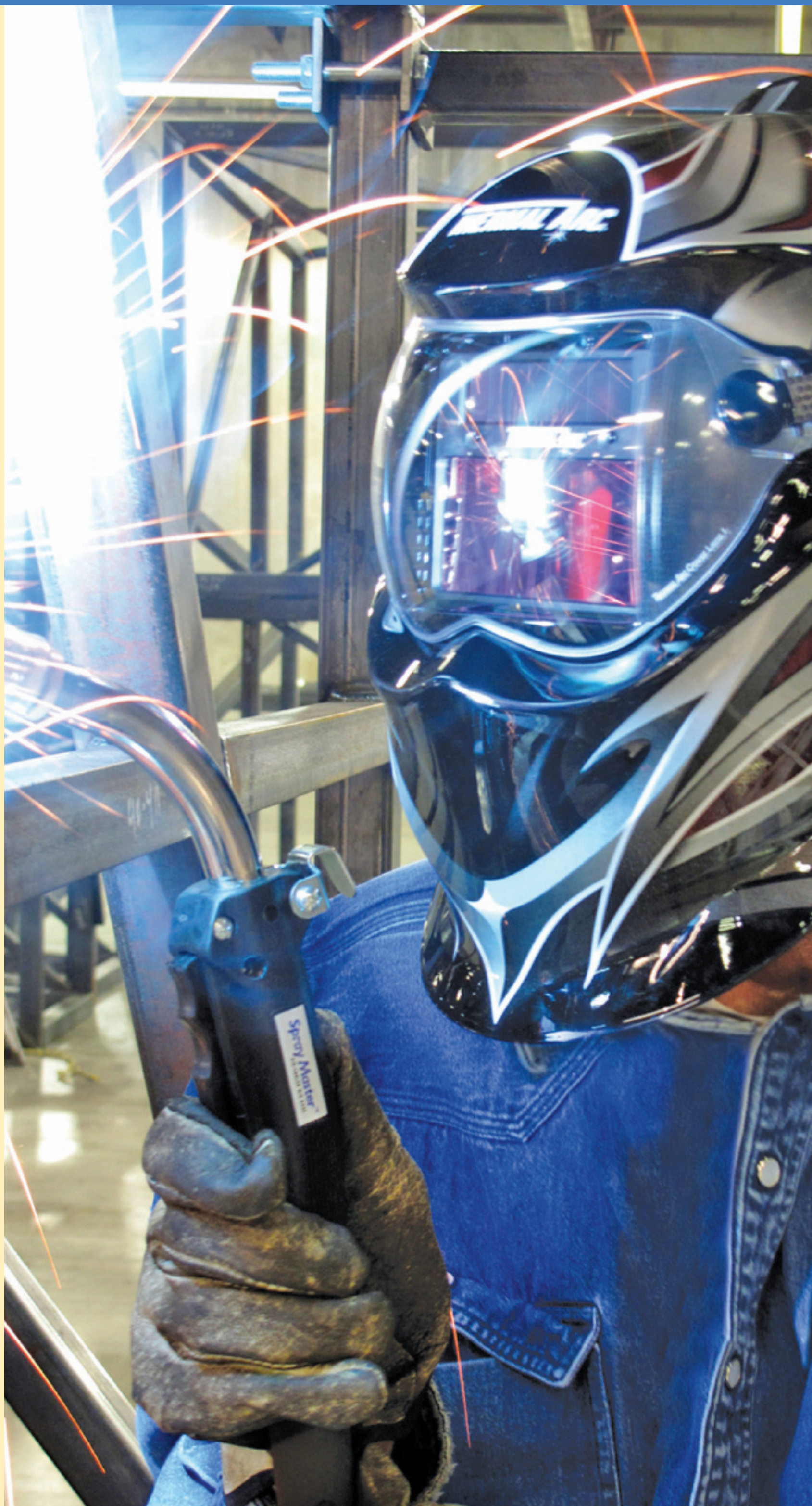
Review

1. Describe the use of the following processes: LBD, LBW, and LBC.
2. How is laser light formed?
3. What type of laser is most often used with a low-power continuous or high-powered pulse?
4. What effect does a material's surface have on the laser beam?
5. Using Table 9-1, what material can be cut with nitrogen?
6. What are reactive laser assist gases called? How do they work?
7. What type of laser beam is used for drilling?
8. What would be one advantage of combining LBW and GMAW?
9. What would be one advantage of combining LBW and GTAW?
10. What is CAC-A?
11. Using Table 9-2, give the recommended procedure for air carbon arc gouging of carbon steel, magnesium alloys, and low alloy copper.
12. Why are some carbon arc electrodes copper-coated?

13. What may occur if an SMA welding machine has below minimum arc voltage for air carbon arc gouging?
14. What is washing, and how can it be used?
15. Why are the chances of receiving arc burns much higher with the shielded metal arc welding process?
16. What is the purpose of U-grooving?
17. How are oxygen lance cuts usually started?
18. What unusual material can be cut with an oxygen lance?
19. What can be added to the water jet stream when cutting hard materials?
20. What applications are arc cutting electrodes used for?

Section 4

Gas Shielded Welding



Success Story

Becoming a welder wasn't a dream 26-year-old Matthew Boomer had when he was younger. Growing up, Matthew had some challenges with his speech. At 17, he took a break from school and went into the working world. He always had in his mind to be independent and successful. He also knew that he would have to embrace education in order to reach these life goals.

When Matthew obtained his GED at the age of 22 he was thinking about which direction he would take his education and career. As part of the GED program at Craven Community College, Matthew qualified to take two free classes. After some thought and discussion with family, he settled on welding classes.

From these first two classes, Matthew went on to seek his welding diploma and several certifications including inert gas welding, handyman welding, and pipe welding. While pursuing this education on a part-time basis, Matthew worked as a welder at Chatsworth Products, Inc., which manufactures metal racks, cabinets, and other products for the computer server market. His employer also paid tuition for six classes, including machining and AutoCAD®.

Matthew graduated in 2015 with a 3.42 grade point average and continues to work at Chatsworth Products. Matthew really enjoys his job and the company he works for. In addition to his welding duties, he is involved in process improvement projects. Recently, he was part of the team that collaborated on a project to cut production time in half by creating and using jigs instead of doing the work by hand. "I want to move up to team lead and maybe, someday, plant manager," said Matthew.

In order to achieve this career path, Matthew will continue his education and continue to improve his speech communications. He plans on pursuing an associate in applied science degree in welding. He is also thinking about getting a business degree because he also has dreams of owning his own business.

In addition to working long hours on second shift and most Saturdays, Matthew enjoys relaxing and staying healthy. He runs, lifts weights, and plays basketball as much as he can. His positive outlook has been reinforced by his education and continues to motivate him to pursue his personal, educational and professional aspirations.

Chapter 10

Gas Metal Arc Welding Equipment, Setup, and Operation

OBJECTIVES

After completing this chapter, the student should be able to

- list the various terms used to describe gas metal arc welding.
- discuss the various methods of metal transfer, including the axial spray metal transfer process, globular transfer, pulsed-arc metal transfer, buried-arc transfer, and short-circuiting transfer GMAW-S.
- list shielding gases used for short-circuiting, spray, and pulsed-spray transfer.
- describe the more commonly used GMA welding filler metals.
- define *deposition efficiency* and tell how a welder can control the deposition rate.
- define *voltage*, *electrical potential*, *amperage*, and *electrical current* as related to GMA welding.
- tell how wire-feed speed is determined and what it affects.
- discuss how the GMAW molten weld pool can be controlled by varying the shielding gas, power settings, weave pattern, travel speed, electrode extension, and gun angle.
- describe the backhand and forehand welding techniques.
- list and describe the basic GMAW equipment.
- explain how the arc spot weld produced by GMAW differs from electric resistance spot welding and the advantages of GMA spot welding.

KEY TERMS

axial spray metal transfer
buried-arc transfer
electrode extension (stickout)
globular transfer
pinch effect
pulsed-arc metal transfer
short-circuiting transfer
slope
synergic systems
transition current

INTRODUCTION

In the 1920s, a metal arc welding process using an unshielded wire was being used to assemble the rear axle housings for automobiles. The introduction of the shielded metal arc welding electrode rapidly replaced the bare wire. The shielded metal arc welding electrode made a much higher-quality weld. In 1948, the first inert gas metal arc welding (GMAW) process, as it is known today, was developed and became commercially available, **Figure 10-1**. In the beginning, the GMAW process was used to weld aluminum using argon (Ar) gas for shielding. As a result, the process was known as MIG, which stands for metal inert gas welding. The later introduction of CO_2 and O_2 to the shielding gas has resulted in the American Welding Society's preferred term, ***gas metal arc welding (GMAW)***. Although the American Welding Society uses the term ***gas metal arc welding*** to describe this process, it is known in the field by several other terms, such as

- *MIG*, which is short for ***metal inert gas welding***,
- MAG, which is short for ***metal active gas welding***, and
- *wire welding*, which describes the electrode used.

The GMAW process may be performed as semiautomatic (SA), machine (ME), or automatic (AU) welding, **Table 10-1**. The GMA welding process is commonly performed as a semiautomatic process and is often mistakenly

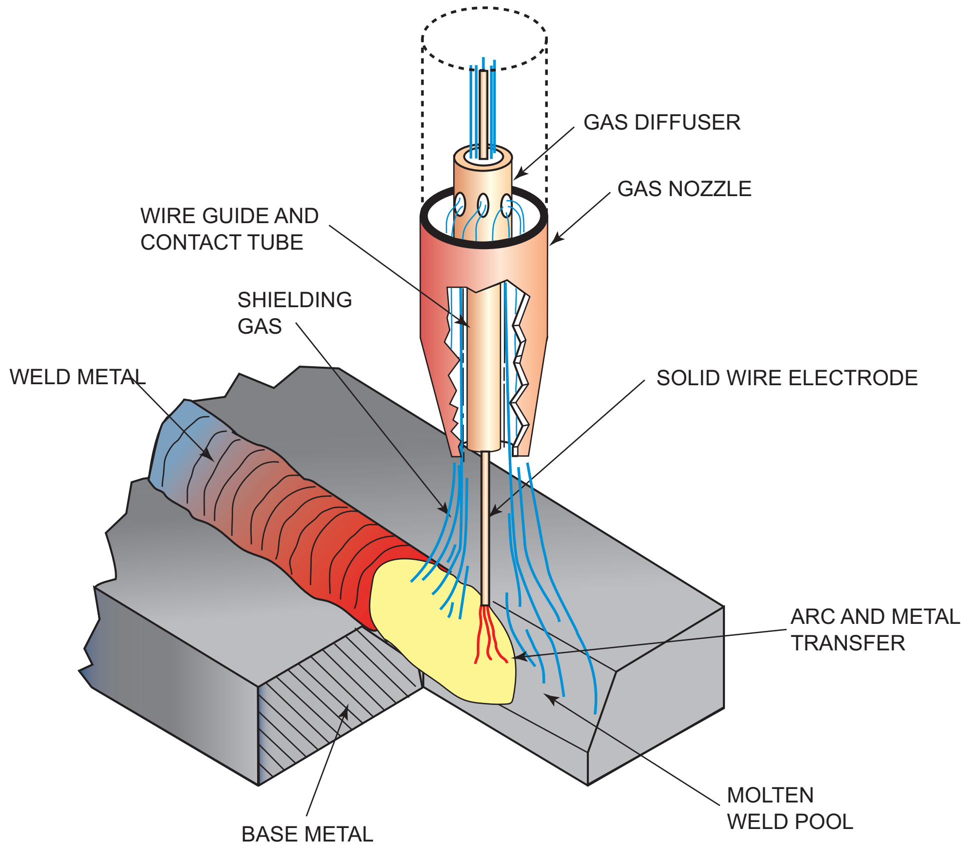


FIGURE 10-1 Gas shielded metal arc welding (GMAW).

Function	Manual (MA) (Example: SMAW)	Semiautomatic (SA) (Example: GMAW)	Machine (ME) (Example: GMAW)	Automatic (AU) (Example: GMAW)
Maintain the arc	Welder	Machine	Machine	Machine
Feed the filler metal	Welder	Machine	Machine	Machine
Provide the joint travel	Welder	Welder	Machine	Machine
Provide the joint guidance	Welder	Welder	Welder	Machine

TABLE 10-1 Methods of Performing Welding Processes

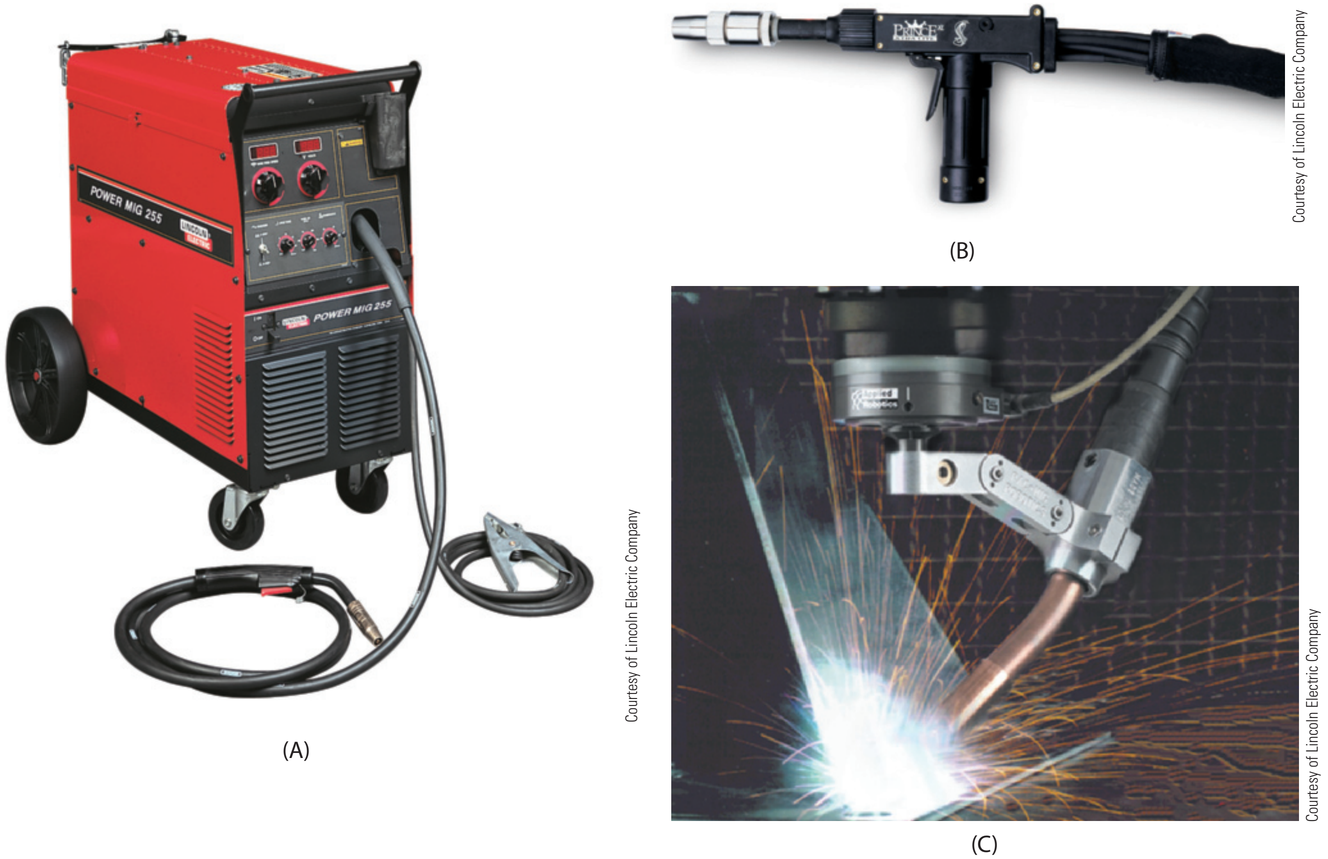


FIGURE 10-2 (A) Semiautomatic GMA welding setup. (B) Machine GMA welding gun with a friction drive, which provides a uniform nozzle to work distance and travel speed. (C) Automatic GMA welding.

referred to as "semiautomatic welding." Equipment is available to perform most of the wire-feed processes semiautomatically, and the GMAW process can be fully automated. Robotic arc welding often uses GMAW because of the adaptability of the process in any position, **Figure 10-2**.

The increasing use of all the various types of consumable wire welding processes has resulted in the increased sales of wire. At one time, wire made up less than 1% of the total market of filler metal. The total tonnage of filler metals used has grown and so has the percentage of wire.

Much of the increase in the use of the wire welding processes is due to the increases in the quality of the welds produced. This improvement is due to the introduction of electronics into the welding machine. Electronics have given the welder more control over the welding parameters. In addition, an increased reliability of the wire-feed systems, improvements in the filler metal, smaller wire sizes, faster welding speed, higher weld deposition rates, less expensive shielding gases, and improved welding techniques. **Table 10-2** shows the typical weld deposition rates using the GMA welding process. The increased usage has led to a reduction in the cost of equipment. GMA welding equipment is now found even in small shops.

Electrode Diameter	Pounds per Hour		
Amperage	0.35	0.45	0.63
50	2.0	—	—
100	4.8	4.2	—
150	7.5	6.7	5.1
200	—	8.7	7.8
250	—	12.7	11.1
300	—	—	14.4

TABLE 10-2 GMA Weld Deposition Rates

In this chapter, the semiautomatic GMA welding process is covered. The skill required to set up and operate this process is basic to the understanding and operation of other wire-feed processes. The reactions of the weld to changes in voltage, amperage, feed speed, stick-out, and gas are similar to those of most wire-feed processes.

WELD METAL TRANSFER METHODS

The GMAW process is unique in that there are six modes of transferring the filler metal from the wire to the weld. Each mode of metal transfer has its own unique characteristics. The mode of metal transfer is the mechanism by which the molten filler metal is transferred across the arc to the base metal. The modes of metal transfer are as follows:

- Short-circuiting transfer (GMAW-S)
- Axial spray transfer
- Globular transfer
- Buried-arc transfer
- Pulsed-arc transfer (GMAW-P)
- Modulated current

To change between short-circuiting, axial spray, globular, or buried arc transfer methods, for the most part all you have to do is make the changes in the welding machines voltage and amperage settings. In some cases it may be necessary to change the shielding gas, but the equipment for all four of these processes is the same.

Pulsed-arc and modulated current transfer methods required welding machines that are specifically designed to provide the specialized voltage and amperage needed to perform these methods of metal transfer.

Selecting the mode of metal transfer used depends on the welding power source, the wire electrode size, type and thickness of material, type of shielding gas used, and the best welding position for the task.

Short-Circuiting Transfer GMAW-S

Low currents allow the liquid metal at the electrode tip to be transferred by direct contact with the molten weld pool. This process requires close interaction between the wire feeder and the power supply. This technique is called **short-circuiting transfer**.

The short-circuiting mode of transfer is the most common process used with GMA welding

- on thin or properly prepared thick sections of material,
- on a combination of thick to thin materials,
- with a wide range of electrode diameters, and
- with a wide range of shielding gases.

The 0.023, 0.030, 0.035, and 0.045 wire electrodes are the recommended diameters for the short-circuiting mode. Shielding gas used on carbon steel is carbon dioxide (CO_2) or a combination of 25% CO_2 and 75% argon (Ar). The amperage range may be as low as 35 for materials of 24 gauge or as high as 225 for materials up to 1/8 in. (3 mm) in thickness on square groove weld joints. Thicker base metals can be welded if the edges are beveled to accept a complete joint weld penetration.

The transfer mechanisms in this process are quite simple and straightforward, as shown schematically in **Figure 10-3**. To start, the wire is in direct contact with the molten weld pool, **Figure 10-3A**. Once the electrode touches the molten weld pool, the arc and its resistance are removed. Without the arc resistance, the welding amperage quickly rises as it begins to flow freely through the tip of the wire into the molten weld pool. The resistance to current flow is highest at the point where the electrode touches the molten weld pool. The resistance is high because both the electrode tip and weld pool are very hot. The higher the temperature, the higher the resistance to current flow. A combination of high current flow and high resistance causes a rapid rise in the temperature of the electrode tip.

As the current flow increases, the interface between the wire and molten weld pool is heated until it explodes into a

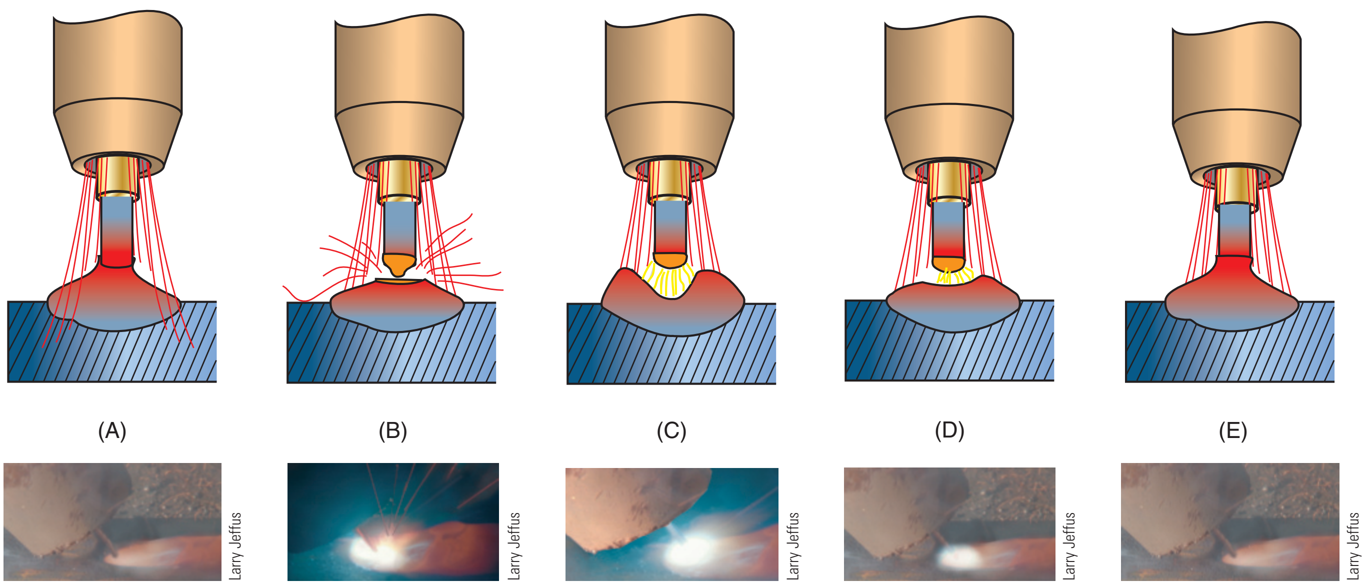


FIGURE 10-3 Schematic of short-circuiting transfer.

vapor, **Figure 10-3B**, establishing an arc. This small explosion produces sufficient force to depress the molten weld pool. A gap between the electrode tip and the molten weld pool, **Figure 10-3C**, immediately opens. With the resistance of the arc reestablished, the voltage increases as the current decreases.

The low current flow is insufficient to continue melting the electrode tip off as fast as it is being fed into the arc. As a result, the arc length rapidly decreases, **Figure 10-3D**, until the electrode tip contacts the molten weld pool, **Figure 10-3E**. The liquid formed at the wire tip during the arc-on interval is transferred by surface tension to the molten weld pool, and the cycle begins again with another short circuit.

If the system is properly tuned, the rate of short circuiting can be repeated from approximately 20 to 200 times per second, causing a characteristic buzzing sound. The spatter is low and the process is easy to use. The low heat produced by GMAW-S makes the system easy to use in all positions on sheet metal, low-carbon steel, low-alloy steel, and stainless steel ranging in thickness from 25 gauge (0.02 in.; 0.5 mm) to 12 gauge (0.1 in.; 2.6 mm). The short-circuiting process does not produce enough heat to make quality welds in sections much thicker than 1/4 in. (6 mm) unless it is used for the root pass on a grooved weld or to fill gaps in joints. Although this technique is highly effective, lack-of-fusion defects can occur unless the process is perfectly tuned and the welder is highly skilled, especially on thicker metal.

Carbon dioxide works well with this short-circuiting process because it produces the forceful arc needed during the arc-on interval to displace the weld pool. Helium can be used as well. Pure argon is not as effective because its arc tends to be sluggish and not very fluid. However, a mixture of 25% carbon dioxide and 75% argon produces a less harsh arc and a flatter, more fluid, and desirable weld profile. Although more costly, this gas mixture is preferred.

New technology in wire manufacturing has allowed smaller wire diameters to be produced. These smaller diameters have become the preferred size even though they are more expensive. The short-circuiting process works better with a short electrode stickout.

The power supply is most critical. It must have a constant potential output and sufficient inductance to slow the time rate of current increase during the short-circuit interval. Too little inductance causes spatter due to high current surges. Too much inductance causes the system to become sluggish. The short-circuiting rate decreases enough to make the process difficult to use. Also, the power supply must sustain an arc long enough to premelt the electrode tip in anticipation of the transfer at recontact with the weld pool.

Globular Transfer

Globular transfer is generally used on thin materials and at a very low current range. In the globular transfer, the arc melts the end of the electrode, forming a molten ball of metal. When the ball of metal becomes so large, its surface tension cannot hold it onto the end of the wire. It falls across the arc most frequently landing in the molten weld pool. Because there is little control over where the glob of metal lands and the weld pool tends to be a small landing target, some globs fall outside of the molten weld pool becoming weld spatter. This process is rarely used by itself because of the large spatter caused by random globs falling outside of the weld. It is used more commonly in combination with pulsed-spray transfer. With this combination of processes, the molten weld pool is larger and the glob is more likely to land in the molten pool, **Figure 10-4**.

Axial Spray Metal Transfer

The **axial spray metal transfer** mode produces high deposition rates with almost spatter-free welds, **Figure 10-5**. This process is identified by the pointing of the wire tip from which very small drops are projected (sprayed) axially across the arc gap to the molten weld pool. There are hundreds of drops per second crossing from the wire to the base metal. These drops are propelled by arc forces at high velocity in the direction the wire is pointing. This projection of drops enables welding in the vertical and overhead positions, if the weld size is kept small, without losing control of transfer.

This spray transfer process requires three conditions: argon shielding (or argon-rich shielding gas mixtures), DCEP polarity, and a current level above a critical amount called the **transition current**. The shielding gas is usually a mixture of 95% to 98% argon and 2% to 5% oxygen. The added percentage of oxygen allows greater weld penetration. **Figure 10-6** illustrates how the rate of drops transferred changes in relationship to the welding current. At low currents, the drops are large and are transferred at rates below 10 per second. These drops move slowly, falling from the electrode tip as gravity pulls them down. They tend to bridge the gap between the electrode tip end and molten weld pool. This produces a momentary short circuit that throws off spatter. However, the mode of transfer changes very abruptly above the critical current, producing the desirable spray. This change in the rate of transfer as related to current is shown schematically in Figure 10-6.

The transition current depends on the alloy being welded. It also is proportional to the wire diameter, meaning that higher currents are needed with larger diameter wires. The high current density imposes some restrictions on the process. For example, it is not practical for welding on sheet metal or thin sections. **Table 10-3** lists the welding parameters for a variety of gases, wire sizes, and metal thicknesses for GMA welding of mild steel.

The spray transfer process generally uses larger diameter wire electrodes with higher amperage ranges for greater production. The higher the amperage range, the faster the weld bead progresses and the faster the joint is filled. The axial spray transfer process is very hot and virtually free of any spatter. The sound produced by axial spray transfer is a quiet, hissing sound, unlike the short-circuit process, which makes a raspy, frying sound. The high welding current produces a great deal of UV light, so you need extra burn protection for your eyes, hands, and arms.

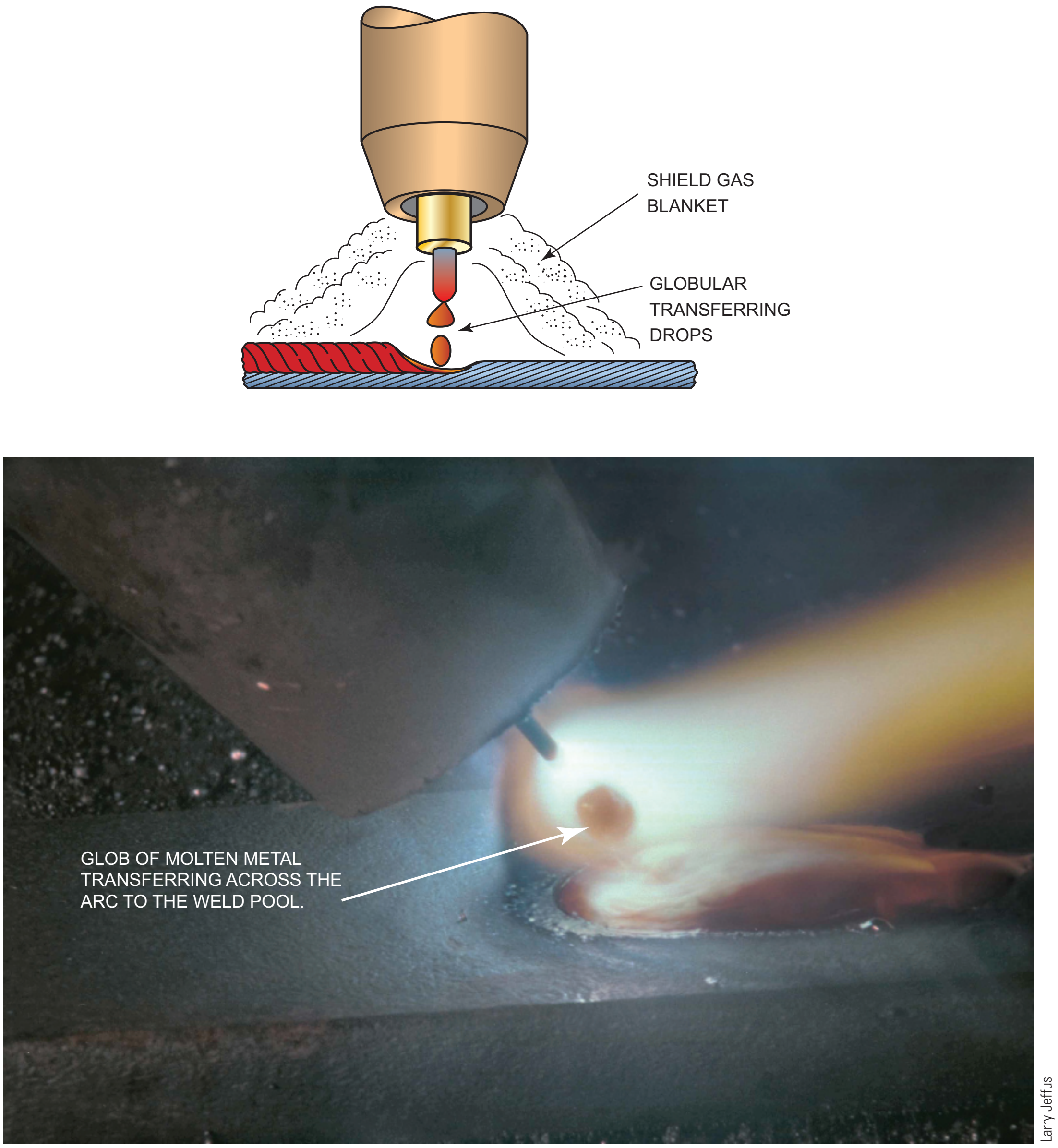


FIGURE 10-4 Globular metal transfer. Large drop is supported by arc forces.

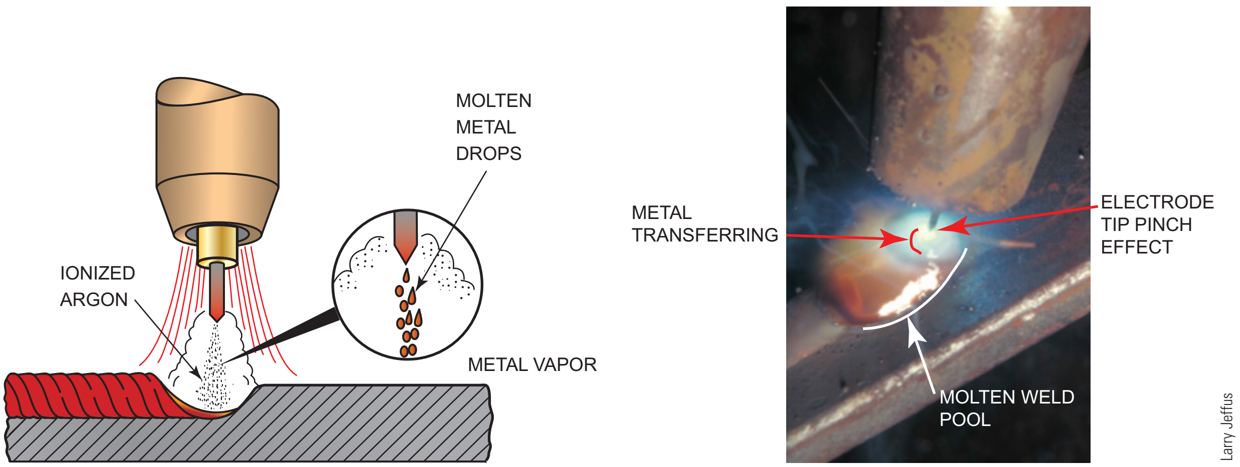


FIGURE 10-5 Axial spray metal transfer. Note the pinch effect of filler wire and the symmetrical metal transfer column.

Mild Steel	Wire-Feed Speed, in./min		Voltage, V				
Base-Material Thickness, in.	0.035-in.	0.045-in.	CO_2	75 Ar-25 CO_2	Ar	98 Ar-2 O_2	Current A
0.036	105-115	—	18	16	—	—	50-60
0.048	140-160	70	19	17	—	—	70-80
0.060	180-220	90-110	20	17.7	—	—	90-110
0.075	240-260	120-130	20.7	18	20	—	120-130
1/8	280-300	140-150	21.5	18.5	20.5	—	140-150
3/16	320-340	160-175	22	19	21.5	23.5	160-170
1/4	360-380	185-195	22.7	19.5	22.5	24.5	180-190
5/16	400-420	210-220	23.5	20.5	23.5	25	200-210
3/8	420-520	220-270	25	22	25	26.5	220-250
1/2 and up	—	375	28	26	29	31	300

TABLE 10-3 GMA Welding Parameters for Mild Steel

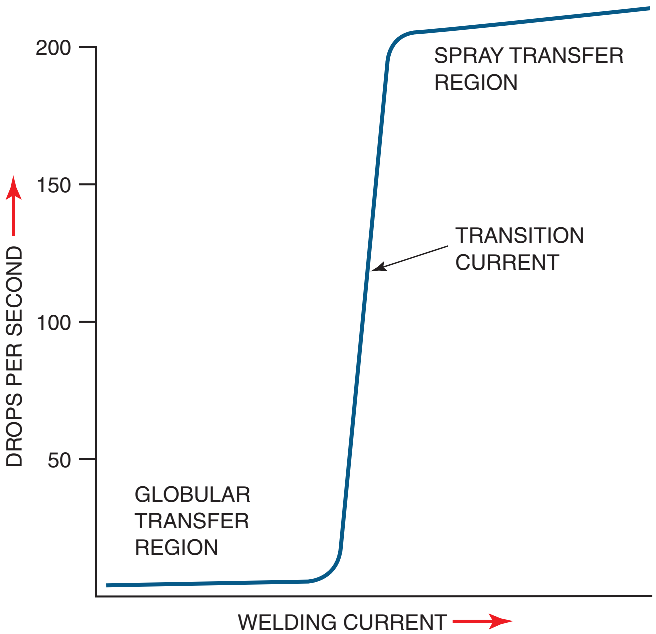


FIGURE 10-6 Desirable spray transfer shown schematically.

CAUTION

The heat produced during axial spray welding using large diameter wire or high current may be intense enough to cause the filter lens in a welding helmet to shatter. Be sure the helmet is equipped with a clear plastic lens on the inside of the filter lens. Avoid getting your face too close to the intense heat.

Pulsed-Arc Metal Transfer

The current produced by the **pulsed-arc metal transfer** (GMAW-P) mode is a dual pulsed current. One pulse of high current is for the axial spray transfer mode, and the other lower pulse of current should not transfer any weld metal, **Figure 10-7**. This pulsing of the current levels permits the use of the high amperage transfer mode and the low amperage so that the total heat input to the weld is lower. The high current of the spray mode produces good

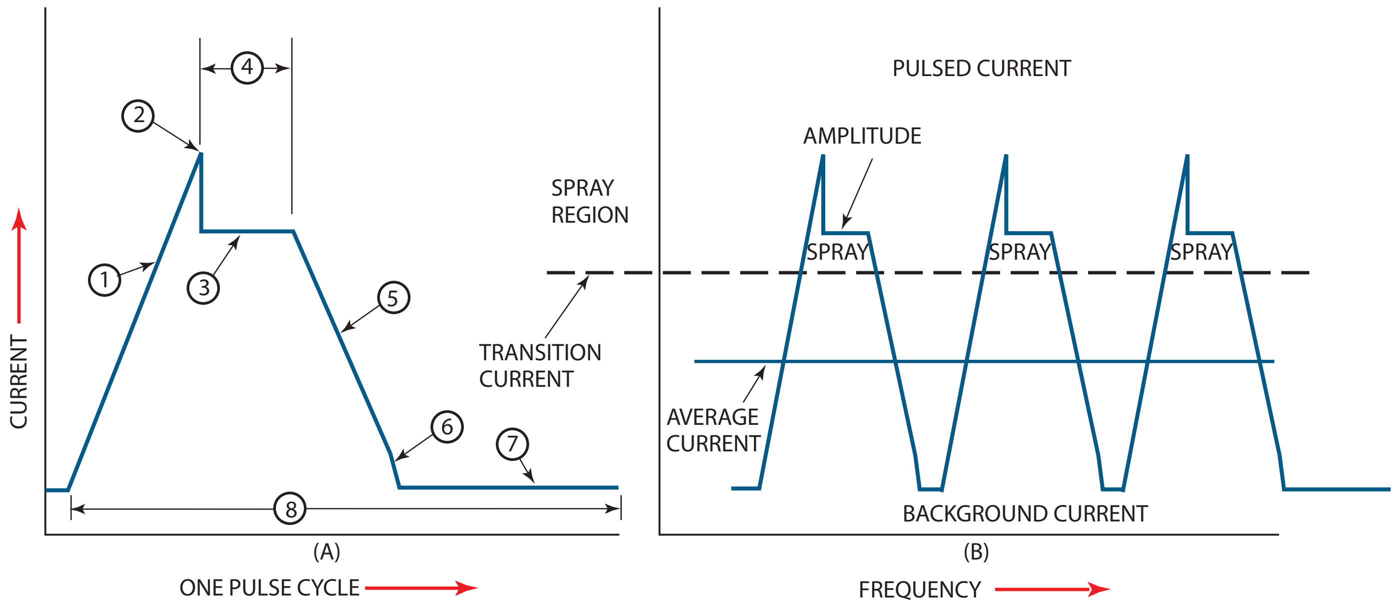


FIGURE 10-7 Mechanism of pulsed arc spray transfer at a low average current.

penetration and fusion, and the low current allows the weld pool to cool and contract slightly, so it is easier to control. The ease of controlling the weld is a major advantage of GMAW-P. Experienced GMA welders can pick up this variation quickly, and new welders often can develop their skills faster on GMAW-P than on traditional GMA welding.

Pulsed-arc welding systems were developed in the mid-1960s, but this technology did not receive much attention until solid state electronics were developed to handle the high power required of welding power supplies. Solid state electronics provided a better, simpler, and more economical way to control the pulsing process. The newest generation of pulsed-arc systems interlocks the power supply and wire feeder so that the proper settings of the wire-feed end power supply are obtained for any given job by adjusting a single knob. Such systems have been termed **synergic systems**. Before pulsed-arc welding machines were programmable, welders had to adjust many of the pulse's components separately. Failure to get the correct setup resulted in a number of welding problems. The newer pulsed-arc welding systems are more complex, but because of the inter-connectivity of the relationship between the wire-feeder and power supply settings, the computer programming makes the operation much easier. Some welders come preprogrammed with the most common settings for metals such as mild steel, stainless steel, and aluminum. Additional programs for welding on specialty metals such as titanium, Inconel, copper, and others can be added from the equipment manufacturer's library of programs or can be created in-house to meet the shop's specific requirements.

GMAW-P can be used to make welds on a wide variety of metals. Most metals can be welded in thicknesses ranging from thin-gauge sheet metal to thick plate. Steel welds can be made using any of the common diameter filler wires with a 1% oxygen and 99% argon shielding gas mixture. Most other metals are welded with 100% argon. The high penetration and great fusion characteristics of the pulsed-arc process work great on aluminum. The process can overcome the high conductivity of aluminum to make thick section welds without preheating.

When the pulsed-arc equipment is equipped with a hot start function, welds can be started without the need for a starting tab because the initial current can be high enough to ensure complete joint penetration and fusion, **Figure 10-8**.

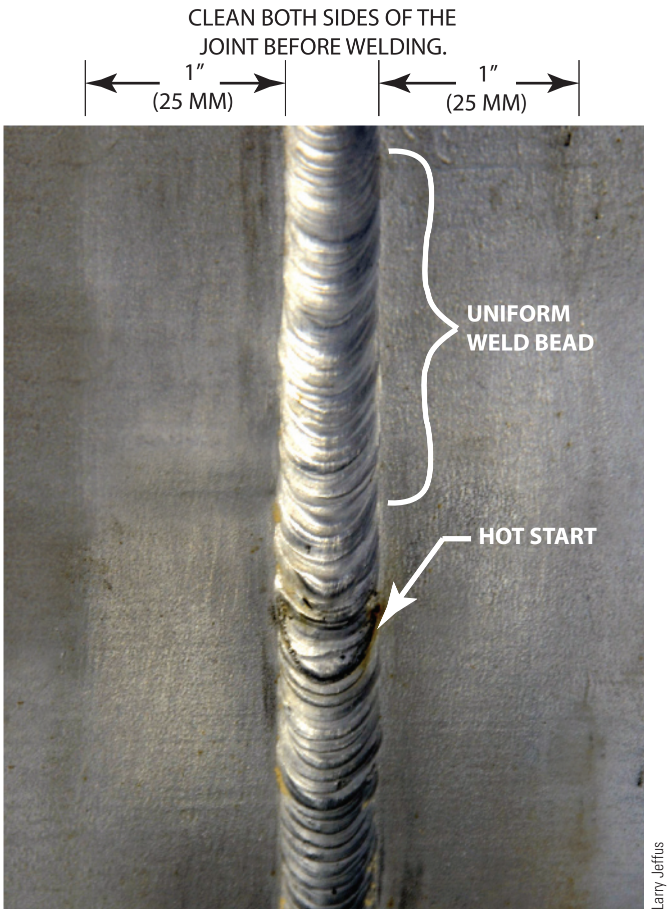


FIGURE 10-8 The hot start helps to make restarting the weld uniform and defect-free.

Pulsed-Arc Metal Transfer Current Cycle

The graph in Figure 10-7 shows the pulse of welding power and identifies the eight components:

1. Ramp up
2. Overshoot
3. High pulse current
4. High pulse time
5. Ramp down
6. Step-off current
7. Background current
8. Pulse width

Figure 10-9 shows the relationship among welding current, metal transfer, and time for the pulses of a typical pulsed-arc transfer.

- **Ramp up** refers to how the electric current in a transformer takes a few milliseconds to build up the magnetic field to full strength once the coil is energized. The rate at which the current builds up the magnetic field and the resulting welding current is called **slope** and is measured in amps/milliseconds. The ramp up or slope can be adjusted on some welding machines. Faster rates are associated with a stiffer, louder, more forceful arc, and lower rates are associated with a softer-sounding arc. As the power ramps up, it starts forming the molten droplet of metal on the electrode tip.
- **Overshoot** refers to the surging electrical current passing through the transformer like a wave on water. The overshoot wave of current has a peak that is higher than the actual welding current. This small peak of power helps start the droplet formation and it adds to the pinch effect required for metal transfer. The higher the percentage the power is overshot, the more rigid the arc and the less likely it is to be deflected by arc blow.

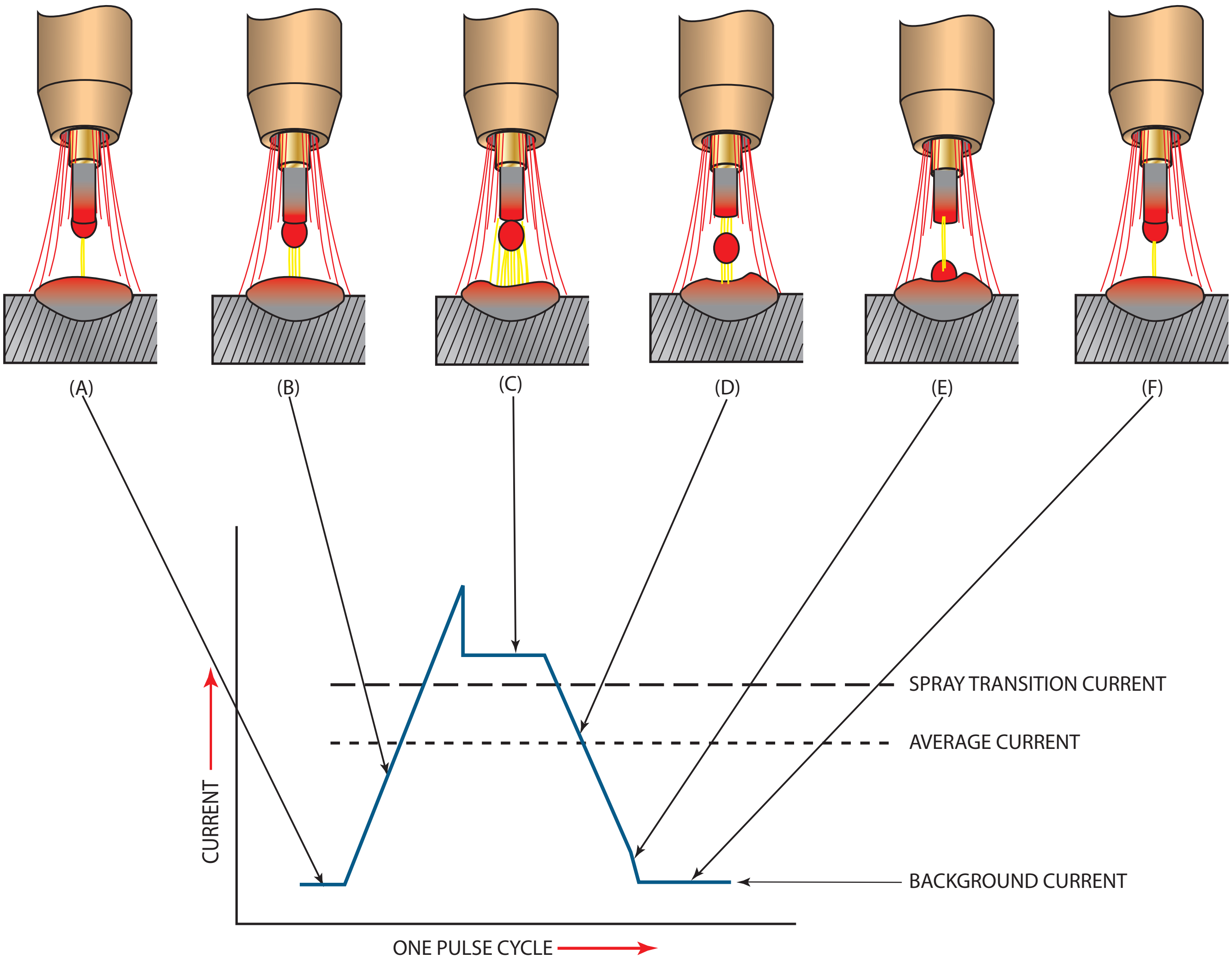


FIGURE 10-9 Pulse-arc metal transfer current cycle.

- **High pulse current** is the peak current that flows across the arc during the high current pulse. It has to be high enough to be above the spray transition current level so that the metal is not transferred in the globular mode. This is the part of the pulse that does the real work of welding. The higher the peak current is, the greater the weld penetration.
- **High current time** is the length of time the peak current is on. It ranges from less than a millisecond to several milliseconds. The longer the high current pulse time, the more likely that multiple droplets of metal will be transferred across the arc. Longer high pulse times will increase penetration and can allow the transfer to become a true spray transfer. If this transformation to spray occurs, then care must be taken to not allow the weld pool to become too large to be controlled in out-of-position welds. The droplets are typically 1- to 1.2-times larger than the diameter of the electrode. As with conventional spray arc, the drops are propelled across the arc gap, allowing metal transfer in all positions.
- **Ramp down** is a function of the time it takes the magnetic field in the transformer to collapse once the coil is de-energized. The magnetic field does not collapse at a uniform rate, but it tends to decay more rapidly at first and slows as it nears the step-off current point. Some manufacturers may depict this line as a concave curve and not linear as in Figure 10-7; however, for all practical purposes, whether it is drawn as a straight linear, logarithmic, or exponential representation, it is the actual de-energizing time in milliseconds that affects the weld. The longer the ramp down time, the more fluid the droplet and molten weld pool will be. Ramp down times range from less than a millisecond to several milliseconds.

NOTE

The time it takes for the magnetic field to build and collapse in a transformer is determined by the size of the iron core and primary and secondary coils. Without inverter technology, which uses a much smaller transformer, the ramp up and ramp down times would be too long for pulsed-arc transfer to work efficiently. The transformer is approximately 7 lb (3 kg) in an inverter welder and approximately 100 lb (45 kg) in a conventional transformer welder.

- **Step-off current** is the point where the final residual magnetic field collapses to the background current. Changes in the step-off current have been associated with arc stability for some higher electrical resistant filler metals such as stainless steel and nickel alloys.
- **Background current** is the lower pulse current that keeps the arc alive between high pulse currents. The higher the background current is, the greater the weld penetration.
- **Pulse width** is the time in milliseconds from the beginning of a single pulse cycle to the beginning of the next cycle. The number of pulses occurring in one second is known as the pulse frequency. Pulse frequency can be adjusted from a few pulses per second to more than 1000 pulses per second.

Because of the complexity and interconnectivity of the pulsed arc's pulse configuration, most of the variables are preset by the manufacturer or are controlled by the welding machine's computer program.

MODULATED CURRENT METAL TRANSFER

Modulated current metal transfer is the newest GMA welding process. It uses an extremely modified version of GMAW-S and has a very sophisticated computer-controlled welding machine. The controller and welding machine together are capable of providing the voltage and amperage required to produce the seven different parts of the complex waveform of power needed to smoothly transfer the molten metal when making a weld, **Figure 10-10**. This method of metal transfer provides the welder a great deal of control over the weld.

The modulated current transfer method of GMA welding has made a major improvement in the efficiency and quality of GMA plate and pipe welds. It can be used to make code-quality welds of metals including carbon steels, stainless steels, and nickel and nickel alloys. In addition, there is a reduction in spatter and fumes associated with conventional GMA welding processes.

The Modulated Current Process

Several manufacturers sell welding equipment designed for the highly specialized welding current profile needed to perform modulated current transfer welding. They all have their own trade names for their version of the modulated current transfer process. There are some differences in how each manufacturer's systems operate, but the theory used to reduce spatter and increase fusion while controlling heat input is similar. In these systems the wire feed speed is constant and the welding current is modulated, controlled up and down, at the same rate that metal is being transferred. The control of the modulated current process is far more sophisticated that the traditional GMAW-P process.

In the modulated current process a sensor is attached near the weld on the plate or pipe. This sensor provides the computer with the necessary information for it to control the metal transfer.

During the welding the computer senses several steps, including:

- When the droplet of molten metal is almost ready to separate from the filler wire and instantly reduces the welding current, as shown by the sharp drop in current between **Figure 10-10C** and **10-10D**.
- Once the arc has been re-established, the computer increases the current back to the higher level for a softer restarting of the arc.
- The higher current level of the re-established arc allows it to melt back the filler metal to form a molten ball of metal on the end.
- After the molten ball is created, the current level is reduced so the end of the wire and molten ball are pushed downward into the molten weld pool.

Advantages of Modulated Current and Pulsed-Arc Metal Transfer

There are a number of advantages that both modulated current and pulsed-arc metal transfer provide to GMA welding.

- **Lower heat input**—The molten weld pool can be larger with both processes because there is actually less heat input to the base metal as a result of the periods of lower current flow. Due to the smoother metal transfer with both during two stages of the metal transfer, the molten pool is not as violently pushed about by the explosive shorting and re-establishment of the arc as it is with GMAW-S. This allows a larger molten weld pool to be easily controlled in any position.
- **Less distortion**—The lower the average current the weld has, the less heat input to the weld, which reduces distortion.
- **Deep penetration**—Despite the lower average welding current, both processes have excellent joint penetration. The high pulse power level on GMAW-P will let you make deep penetrating welds on thick sections of aluminum in many applications without preheating the part.
- **Higher travel speeds**—Faster travel speeds are possible on all thicknesses of metal.
- **Poor fit-up**—The modulated current transfer process can be used to make code-quality root welds even if the root opening and root face may vary as much as the code might allow. It can push through a small root gap at one point and not burn through a wider gap in another spot.
- **Reduced spatter**—Both process have lower spatter. The lack of any significant spatter will result in less

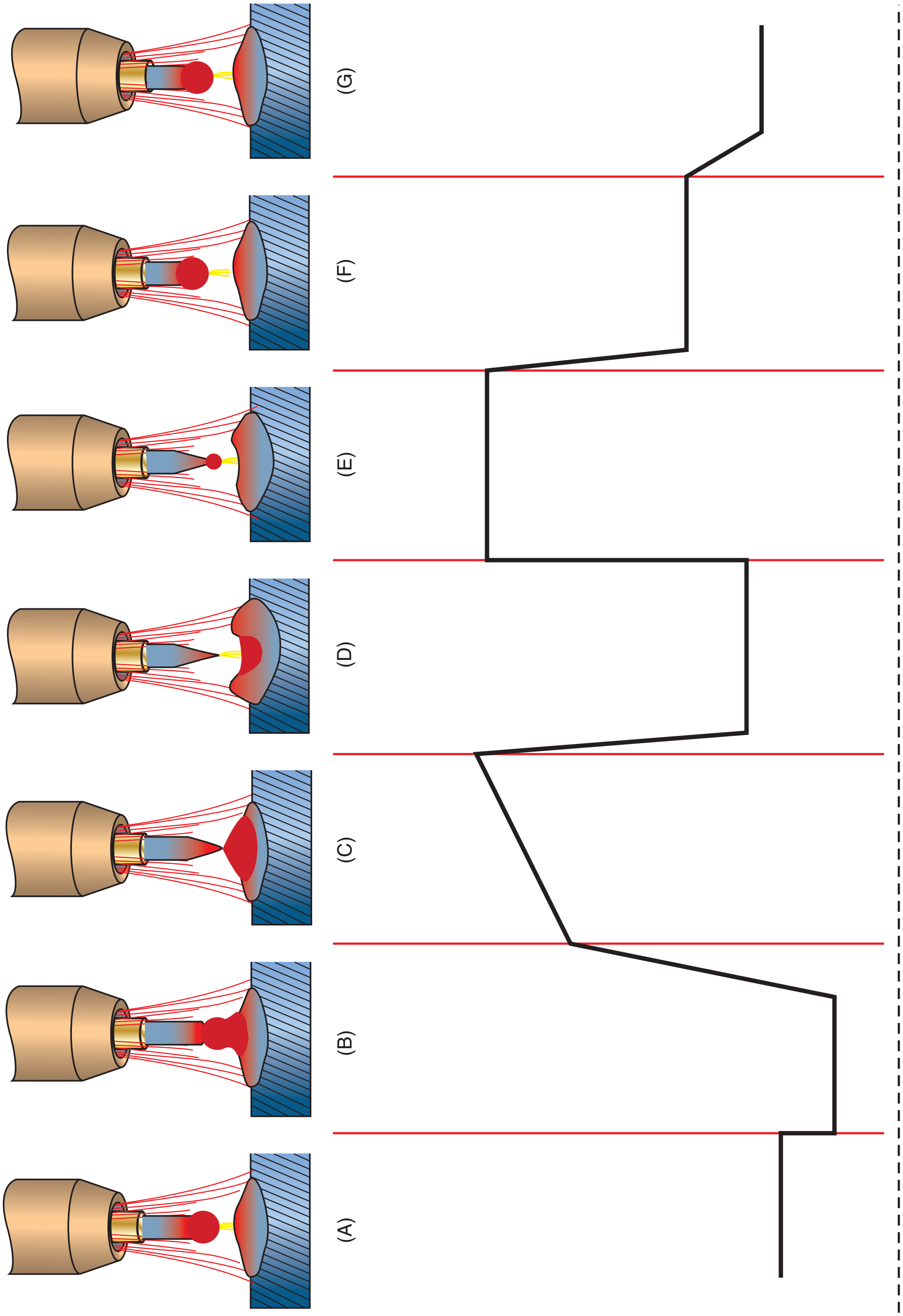


FIGURE 10-10 Modulated current welding cycle diagram.

postwelding cleanup of the parts, longer-lasting gun parts, and a reduction of spatter buildup on jigs and fixtures.

- **High transfer efficiency**—The reduction in spatter means that more of the filler metal is transferred to the weld. In many applications, 98% transfer efficiencies can be obtained, which reduces wasted filler metal.
- **Lower fume production**—There is little fume produced during welding, which means less shop air pollution.
- **High-quality welds**—The weld deposits have little chance of hydrogen entrapment, have good fusion and weld appearance, and have improved impact test values.
- **Arc blow resistant**—The arc is very stable and resistant to arc blow. Part of the arc blow resistance comes from the pulsing current, and some comes from the shorter arc length. The arc length must be just long enough so that the end of the electrode or metal being transferred across the arc does not short out. Once the arc length is set, slight variations in gun height will not affect the arc length. This is particularly beneficial when welding through an inside corner where gun access and welder visibility might be limited.

Welders find the welding environment with little spatter, fumes, and reduced heat more pleasant to work in than most other welding processes.

Buried-Arc Transfer

The arc in carbon dioxide is very forceful. Because of this, the wire tip can be driven below the surface of the molten weld pool. With the shorter arcs, the drop size is small, and any spatter produced as the result of short circuits is trapped in the cavity produced by the arc, hence the name **buried-arc transfer**, **Figure 10-11**. The resultant welds tend to be more highly crowned than those produced with open arcs, but they are relatively free of spatter and offer a decided advantage of welding speed. These characteristics make the buried-arc process useful for high-speed mechanized welding of thin sections, such as that found in compressor domes for hermetic air conditioning and refrigeration equipment or for automotive components.

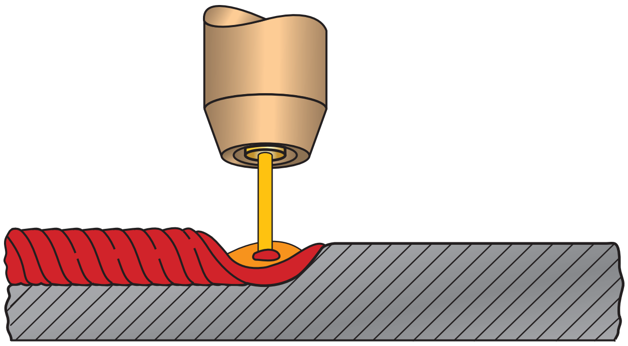


FIGURE 10-11 Buried-arc transfer. Wire tip is with the weld crater. Spatter is trapped.

GMAW FILLER METAL SPECIFICATIONS

GMA welding filler metals are available for a variety of metals, **Table 10-4**. The most frequently used filler metals are AWS specification A5.18 for carbon steel and AWS specification A5.9 for stainless steel. Wire electrodes are produced in 0.023, 0.030, 0.035, 0.045, and 0.062 diameters. Other larger diameters are available for production work and can include wire diameter sizes such as 1/16, 5/64, and 7/64 in. **Table 10-5** lists the most common sizes and the amperage ranges for these electrodes. The amperage will vary depending on the method of metal transfer, type of shielding gas, and base metal thickness. Some steel wire electrodes have a thin copper coating. This coating provides some protection to the electrode from rusting and improves the electrical contact between the wire electrode and the contact tube. They may look like copper wire because of the very thin copper cladding. The amount of copper is so small that it either burns off or is diluted into the weld pool with no significant effect on the weld bead.

For more information regarding each of the GMA welding electrodes, refer to Chapter 27 (Filler Metal Selection).

Base Metal Type	AWS Filler Metal Specification
Aluminum and aluminum alloys	A5.10
Copper and copper alloys	A5.6
Magnesium alloys	A5.19
Nickel and nickel alloys	A5.14
Stainless steel (austenitic)	A5.9
Steel (carbon)	A5.18
Titanium and titanium alloys	A5.16

TABLE 10-4 AWS Filler Metal Specifications for Different Base Metals

Base Metal	Electrode Diameter		Amperage
	Inch	Millimeter	Range
Carbon steel	0.023	0.6	35-190
	0.030	0.8	40-220
	0.035	0.9	60-280
	0.045	1.2	125-380
	1/16	1.6	275-450
Stainless steel	0.023	0.6	40-150
	0.030	0.8	60-160
	0.035	0.9	70-210
	0.045	1.2	140-310
	1/16	1.6	280-450

TABLE 10-5 Filler Metal Diameters and Amperage Ranges

WIRE MELTING AND DEPOSITION RATES

The wire melting rates, deposition rates, and wire-feed speeds of the consumable wire welding processes are affected by the same variables. Before discussing them, however, these terms need to be defined. The wire melting rate, measured in inches per minute (in./min) or pounds per hour (lb/hr), is the rate at which the arc consumes the wire. The deposition rate, the measure of weld metal deposited, is nearly always less than the melting rate because not all of the wire is converted to weld metal. Some is lost as slag, spatter, or fume. The amount of weld metal deposited in ratio to the wire used is called the *deposition efficiency*.

THINK GREEN

Reduce Waste of Filler Metals

GMA welding's 98% deposition rate of filler metal into the weld makes it one of the most efficient welding processes. Filler metal carries a high cost when it does not get deposited into the weld because of spatter or electrode stubs and it becomes wasted material. Using GMA welding will reduce waste.

Deposition efficiencies depend on the process, on the gas used, and even on how the welder sets welding conditions. With efficiencies of approximately 98%, solid wires with argon shields are best.

Welders can control the deposition rate by changing the current, electrode extension, and diameter of the wire. To obtain higher melting rates, they can increase the current or wire extension or decrease the wire diameter. Knowing the precise constants is unimportant. However, it is important to know that current greatly affects melting rate and that the extension must be controlled if results are to be reproducible.

WELDING POWER SUPPLIES

To better understand terminology used to describe the different welding power supplies, you need to know the following electrical terms:

- Voltage, or volts (V), is a measurement of electrical pressure in the same way that pounds per square inch is a measurement of water pressure.
- Electrical potential means the same thing as voltage and is usually expressed by using the term ***potential*** *(P)*. The terms *voltage*, *volts*, and *potential* can all be interchanged when referring to electrical pressure.
- Amperage, or amps (A), is the measurement of the total number of electrons flowing in the same way that gallons are a measurement of the amount of water flowing.
- Electrical current means the same thing as amperage and is usually expressed by using the term ***current*** *(C)*. The terms ***amperage***, ***amps***, and ***current*** can all be interchanged when referring to electrical flow.

GMA Welding Machines

GMAW power supplies are the constant-voltage, constant-potential (CV, CP) type of machines, unlike SMAW power supplies, which are the constant-current (CC) type of machines and are sometimes called drooping arc voltage (DAV). It is impossible to make acceptable welds using the wrong type of power supply. Constant-voltage power supplies are available as transformer-rectifiers or as motor-generators, **Figure 10-12**. Some newer machines use electronics, enabling them to supply both types of power at the flip of a switch.

The relationships between current and voltage with different combinations of arc length or wire-feed speeds are called volt-ampere characteristics. The volt-ampere characteristics of arcs in argon with constant arc lengths or constant wire-feed speeds are shown in **Figure 10-13**. To maintain a constant arc length while increasing current, it is necessary to increase voltage. For example, with a 1/8-in. (3-mm) arc length, increasing current from 150 to 300 amperes requires a voltage increase from approximately 26 to 31 volts. The current increase

Courtesy of ESAB Welding & Cutting Products

FIGURE 10-12 Transformer-rectifier welding power supply.

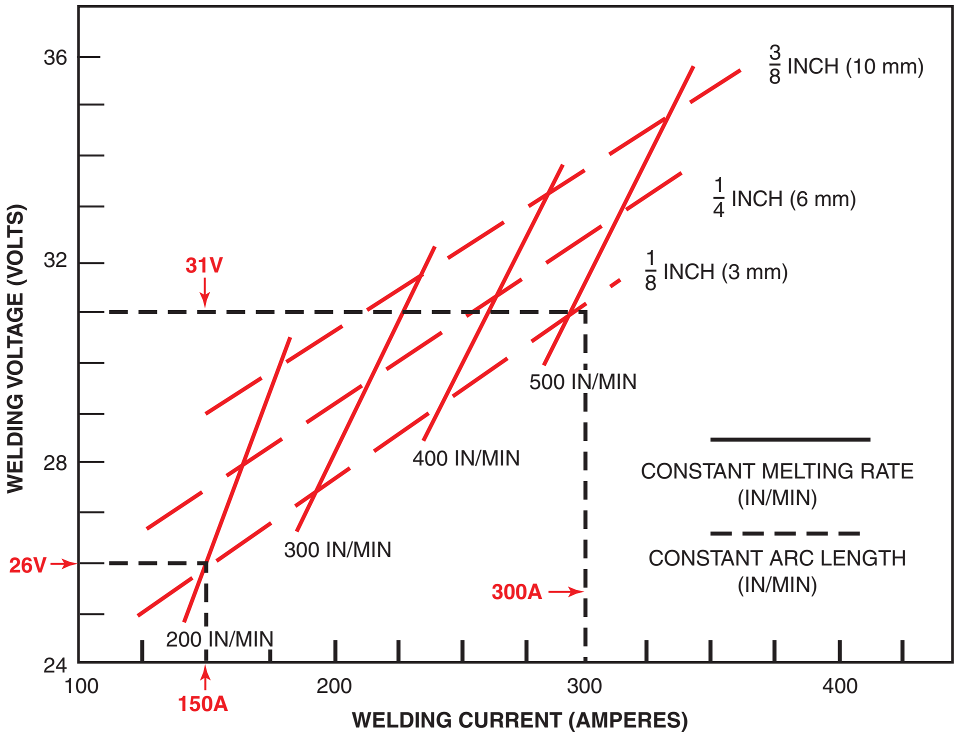


FIGURE 10-13 The arc length and arc voltage are affected by the welding current and wire feed speed (.045-in. [1.43-mm] wire; 1-in. [25-mm] electrode extension).

illustrated here results from increasing the wire-feed speed from 200 in. to 500 in. per minute (5 m/min to 13 m/min).

Speed of the Wire Electrode

The wire-feed speed is generally recommended by the electrode manufacturer and is selected in inches per minute (ipm), or how fast the wire exits the contact tube. The welder uses a wire speed control dial on the wire-feed unit to control ipm. It can be advanced or slowed to control the burn-off rate, or how fast the electrode transfers into the weld pool, to meet the welder's skill in controlling the weld pool, **Table 10-6**.

To accurately measure wire-feed ipm, snip off the wire at the contact tube. Squeeze the trigger for 6 seconds; release and snip off the wire electrode. Measure the number of inches of wire that was fed out during the six seconds. Using basic shop math, multiply its total length in inches by 10. The result is how many inches of wire were fed per minute.

Power Supplies for Short-Circuiting Transfer

Although the GMA power source is said to have a constant potential (CP), it is not perfectly constant. The graph in **Figure 10-14** shows that there is a slight decrease in voltage

Wire-Feed Speed* in./min (m/min)	Wire Diameter Amperages			
	0.030 in. (0.8 mm)	0.035 in. (0.9 mm)	0.045 in. (1.2 mm)	0.062 in. (1.6 mm)
100 (2.5)	40	65	120	190
200 (5.0)	80	120	200	330
300 (7.6)	130	170	260	425
400 (10.2)	160	210	320	490
500 (12.7)	180	245	365	—
600 (15.2)	200	265	400	—
700 (17.8)	215	280	430	—

*To check feed speed, run out wire for 1 minute and then measure its length.

TABLE 10-6 Typical Amperages for Carbon Steel

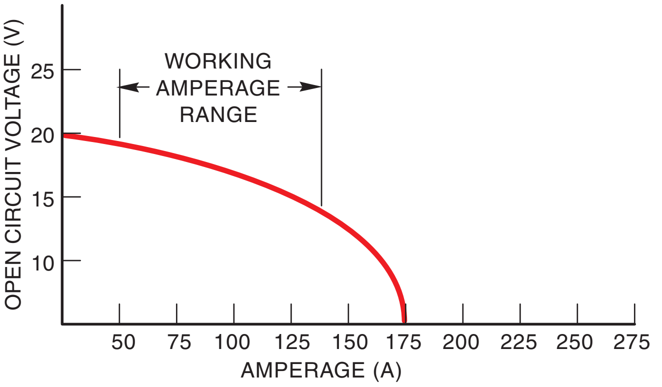


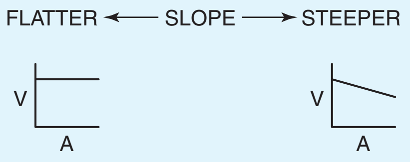
FIGURE 10-14 Constant potential welder slope.

as the amperage increases within the working range. The rate of decrease is known as slope. It is expressed as the voltage decrease per 100-ampere increase—for example, 10 V/100 A. For short-circuiting welding, some are equipped to allow changes in the slope by steps or continuous adjustment.

The slope, which is called the ***volt-ampere curve***, is often drawn as a straight line because it is fairly straight within the working range of the machine. Whether it is drawn as a curve or a straight line, the slope can be found by finding two points. The first point is the set voltage as read from the voltmeter when the gun switch is activated but no welding is being done. This is referred to as the ***open circuit voltage***. The second point is the voltage and amperage as read during a weld. The voltage control is not adjusted during the test but the amperage can vary. The slope is the voltage difference between the first and second readings. The difference can be found by subtracting the second voltage from the first voltage. Therefore, for settings over 100 amperes, it is easier to calculate the slope by adjusting the wire feed so that you are welding with 100 amperes, 200 amperes, 300 amperes, and so on. In other words, the voltage difference can be simply divided by 1 for 100 amperes, 2 for 200 amperes, and so forth.

The machine slope is affected by circuit resistance. Circuit resistance may result from a number of factors, including poor connections, long leads, or a dirty contact tube. A higher resistance means a steeper slope. In short-circuiting machines, increasing the inductance increases the slope. This increase slows the current's rate of change during short circuiting and the arcing intervals, **Figure 10-15**. Therefore, slope and inductance become synonymous in this discussion. As the slope increases, both the short-circuit current and **pinch effect** are reduced. A flat slope has both an increased short-circuit current and a greater pinch effect.

The machine slope affects the short-circuiting metal transfer mode more than it does the other modes. Too much current and pinch effect from a flat slope cause a violent short and arc restart cycle, which results in increased spatter. Too little current and pinch effect from a steep slope result in the short circuit not being cleared as the wire freezes in the molten pool and piles up on the work, **Table 10-7**.



Buildup	Decreases	Increases
Depth of fusion	Increases	Decreases
Spatter	Increases	Decreases
Shorting	Violently cleared	May not clear

TABLE 10-7 Effect of Slope

The slope should be adjusted so that a proper spatter-free metal transfer occurs. On machines that have adjustable slopes, this is easily set. On machines that have a fixed slope it is possible to vary the contact tube-to-work distance to affect the welding resistance. The GMA filler wire is much too small to carry the welding current and heats up due to its resistance to the current flow. The greater the tube-to-work distance, the greater the circuit resistance and the steeper the slope. By increasing or decreasing this distance, a proper slope can be obtained so that the short circuiting is smoother and has less spatter.

SHIELDING GAS

The shielding gas selected for a weld has a definite effect on the weld produced. The properties that can be affected include the method of metal transfer, welding speed, weld contour, arc cleaning effect, and fluidity of the molten weld pool.

In addition to the effects on the weld itself, the metal to be welded must be considered in selecting a shielding gas. Some metals must be welded with an inert gas such as argon or helium or mixtures of argon and helium. Other metals weld more favorably with reactive gases such as carbon dioxide or with mixtures of inert gases and reactive gases such as argon and oxygen or argon and carbon dioxide,

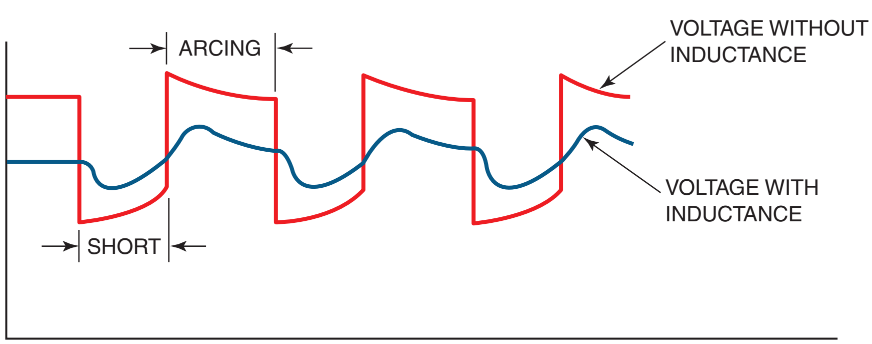


FIGURE 10-15 Voltage pattern with and without inductance.

GMAW Metals, Shielding Gases, and Gas Blends														
Metals	Gases		Blends of Two Gases									Blends of Three Gases		
			Argon + Oxygen			Argon + Carbon Dioxide			Argon + Helium					
	Argon (Ar)	CO_2	Ar + 1% O_2	Ar + 2% O_2	Ar + 5% O_2	Ar + 5% CO_2	Ar + 10% CO_2	Ar + 25% CO_2	Ar + 25% He	Ar + 50% He	Ar + 75% He	Ar + CO_2 + O_2	Ar + CO_2 + Nitrogen	Ar + CO_2 + Helium
Aluminum	X								X	X	X			X
Copper alloys	X								X	X	X			
Stainless steel		X	X	X	X			X			X	X	X	X
Steel		X	X	X	X	X	X	X	X			X		
Magnesium	X							X	X	X	X			
Nickel alloys	X								X	X	X			

(A)

GMAW Shielding Gases, Gas Blends, Metals, and Welding Process							
Gases/Blend	Gas Reaction	Application	Remarks	Gas/Blend	Gas Reaction	Application	Remarks
Argon (Ar)	Inert	Nonferrous metals	Provides spray transfer	CO_2	Oxidizing	Mild, low alloy steels and stainless steel	Least expensive gas, deep penetration with short-circuiting or globular transfer
Helium (He)	Inert	Aluminum and magnesium	Very hot arc for welds on thick sections, usually used in gas blends to increase the arc temperature and penetration	Nitrogen	Almost inert	Copper and copper alloys	Has high heat input with globular transfer
Ar + 1% O_2	Oxidizing	Stainless steel	Oxygen provides arc stability	Ar + 25% He	Inert	Al, Mg, copper, nickel, and their alloys	Higher heat input than Ar, for thicker metal
Ar + 2% O_2	Oxidizing	Stainless steel	Oxygen provides arc stability	Ar + 50% He	Inert	Al, Mg, copper, nickel, and their alloys	Higher heat in arc use on heavier thickness with spray transfer
Ar + 5% O_2	Oxidizing	Mild and low alloy steel	Provides spray transfer	Ar + 75% He	Inert	Copper, nickel, and their alloys	Highest heat input
Ar + 5% CO_2	Oxidizing	Low alloy steel	Pulse spray and short-circuit transfer in out-of-position welds	Ar + CO_2 + O_2	Oxidizing	Low alloy steel and some stainless steels	All metal transfer for automatic and robotic applications
Ar + 10% CO_2	Oxidizing	Low alloy steel	Same as above with a wider, more uid weld pool	Ar + CO_2 + N	Almost inert	Stainless steel	All metal transfer, excellent for thin gauge material
Ar + 25% CO_2	Oxidizing	Mild, low alloy steels and stainless steel	Smooth weld surface, reduces penetration with short-circuiting transfer	He + Ar + CO_2	Almost inert	Stainless steel and some low alloy steels	Excellent toughness; excellent arc stability, wetting characteristics, and bead contour; little spatter with short-circuiting transfer

(B)

TABLE 10-8 GMAW Shielding Gases and Base Metals

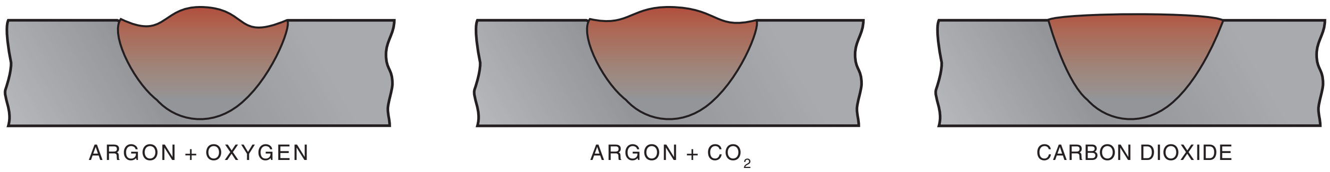


FIGURE 10-16 Effect of shielding gas on weld bead shape.

Table 10-8. The most commonly used shielding gases are 75% argon + 25% CO_2, argon + 1% to 5% oxygen, and carbon dioxide, **Figure 10-16**.

Argon

The atomic symbol for argon is *Ar*, and it is an inert gas. *Inert gases* do not react with any other substance and are insoluble in molten metal. One-hundred percent argon is used on nonferrous metals such as aluminum, copper, magnesium, nickel, and their alloys, but 100% argon is not normally used for making welds on ferrous metals.

Argon is denser than air so it effectively shields welds by pushing the lighter air away. Argon is relatively easy to ionize. Easily ionized gases can carry long arcs at lower voltages. This makes it less sensitive to changes in arc length. Argon gas is naturally found in all air and is collected in air separation plants. There are two methods of separating air to extract nitrogen, oxygen, and argon. In the cryogenic process, air is supercooled to temperatures that cause it to liquefy and the gases are separated. In the noncryogenic process, molecular sieves (strainers with very small holes) separate the various gases much like using a screen to separate sand from gravel. The cathodic cleaning action associated with argon at DCEP (DCRP) is also very important for fabricating metals such as aluminum. Aluminum forms a heavy, undesirable surface oxide when heated and exposed to air.

Argon shielding gas or mixtures of argon and other gases are required for the axial spray transfer process. Common argon shielding gas mixtures used for steel contain helium and/or oxygen.

Argon Gas Blends

Oxygen, carbon dioxide, helium, and nitrogen can be blended with argon to change argon's welding characteristics. Adding reactive gases (oxidizing), such as oxygen or carbon dioxide,

to argon tends to stabilize the arc, promote favorable metal transfer, and minimize spatter. As a result, the penetration pattern is improved, and undercutting is reduced or eliminated. Adding helium or nitrogen gases (nonreactive or inert) increases the arc heat for deeper penetration.

The amount of the reactive gases, oxygen or carbon dioxide, required to produce the desired effects is quite small. As little as a half a percent change in the amount of oxygen will produce a noticeable effect on the weld. Most of the time blends containing 1% to 5% of oxygen are used. Carbon dioxide may be added to argon in the range of 20% to 30%. Blends of argon with less than 10% carbon dioxide may not have enough arc voltage to give the desired results. The most commonly used argon CO_2 blend is 25% CO_2.

When using oxidizing shielding gases with oxygen or carbon dioxide added, a suitable filler wire containing deoxidizers should be used to prevent porosity in the weld. The presence of oxygen in the shielding gas can also cause some loss of certain alloying elements, such as chromium, vanadium, aluminum, titanium, manganese, and silicon.

The cathodic cleaning action of 100% argon causes problems with steels. Iron oxide in and on the steel surface can be a good emitter of electrons that may attract the arc. However, these oxides are not uniformly distributed, resulting in very irregular arc movement and, in turn, irregular weld deposits. This problem was solved by adding small amounts of oxygen to the argon. The reaction produces a uniform film of iron oxide on the weld pool and provides a stable site for the arc. This discovery enabled uniform welds in ferrous alloys and expanded the use of GMAW to welding those materials.

The amount of oxygen needed to stabilize arcs in steel varies with the alloy. Generally, 2% is sufficient for carbon and low-alloy steels. In the case of stainless steels, approximately 0.5% should prevent a refractory scale of chromium oxide. Carbon dioxide can substitute for oxygen. More than 2% is needed, however, and 8% appears to be optimum for low-alloy steels. In many applications, carbon dioxide is the preferred addition because the weld bead has a better contour and the arc appears to be more stable.

HELIUM

The atomic symbol for helium is *He*, and it is an inert gas that is a product of the natural gas industry. It is removed from natural gas as the gas undergoes separation (fractionation) for purification or refinement.

Helium is lighter than air; thus, its flow rates must be approximately twice as high as that of argon for acceptable stiffness in the gas stream to be able to push air away from the weld. Proper protection is difficult in drafts unless high flow rates are used. It requires a higher voltage to ionize, which produces a much hotter arc. There is a noticeable increase in both the heat and temperature of a helium arc. This hotter arc makes it easier to make welds on thick sections of aluminum and magnesium.

Small quantities of helium are blended with other heavier gases. These blends take advantage of the heat produced by the lightweight helium and weld coverage by the other heavier gas. Thus, each gas is contributing its primary advantage to the blended gas.

Helium/argon mixtures may contain as much as 80% helium. The helium is added to the argon to increase the power in the arc without affecting the desirable qualities of the spray mode. With more helium, the transfer becomes progressively more globular, forcing the use of a different welding mode (to be described later). Because helium and argon gases are inert, they do not react chemically with any metals.

Carbon Dioxide

Carbon dioxide is a compound made up of one carbon atom (C) and two oxygen atoms (O_2), and its molecular formula is CO_2. One-hundred percent carbon dioxide is widely used as a shielding gas for GMA welding of steels. It allows higher welding speed, better penetration, good mechanical properties, and costs less than the inert gases. The chief drawback in the use of carbon dioxide is the less-steady arc characteristics and a considerable increase in weld spatter. The spatter can be kept to a minimum by maintaining a very short, uniform arc length. CO_2 can produce sound welds provided that a filler wire with the proper deoxidizing additives is used.

Nitrogen

The atomic symbol for nitrogen is *N*. It is not an inert gas, but it is relatively nonreactive to the molten weld pool. It is often used in blended gases to increase the arc's heat and temperature. One-hundred percent nitrogen can be used to weld copper and copper alloys.

THINK GREEN

Renewable Gases

Argon, nitrogen, and oxygen GMA shielding gases are refined from air in our atmosphere and are returned to the atmosphere in almost the exact condition as they leave the welding zone. Because argon is an inert gas, it is returned to the atmosphere in the exact same condition as it was. Nitrogen may pick up some oxygen atoms, and oxygen may pick up some metal oxides, but most of the shielding gas is unchanged.

POWER SETTINGS

As the power settings, voltage, and amperage are adjusted, the weld bead is affected. Making an acceptable weld requires a balancing of the voltage and amperage. If either or both are set too high or too low, the weld penetration can decrease. A GMA welding machine has no direct amperage settings. Instead, the amperage at the arc is adjusted by

changing the wire-feed speed. As a result of the welding machine maintaining a constant voltage when the wire-feed speed increases, more amperage flows across the arc. This higher amperage is required to melt the wire so that the same arc voltage can be maintained. The higher amperage is used to melt the filler wire and does not increase the penetration. In fact, the weld penetration may decrease significantly.

Increasing and decreasing the voltage change the arc length but may not put more heat into the weld. Like changes in the amperage, these voltage changes may decrease weld penetration.

WEAVE PATTERN

The GMA welding process is greatly affected by the location of the electrode tip and molten weld pool. During the short-circuiting process, if the arc is directed to the base metal and outside the molten weld pool, then the welding process may stop. Without the resistance of the hot molten metal, high amperage surges occur each time the electrode tip touches the base metal, resulting in a loud pop and a shower of sparks. It is something that occurs each time a new weld is started. So, when making the weave pattern, you must keep the arc and electrode tip directed into the molten weld pool. Other than the sensitivity to arc location, most of the SMAW weave pattern can be used for GMA welds.

TRAVEL SPEED

Because the location of the arc inside the molten weld pool is important, the welding travel speed cannot exceed the ability of the arc to melt the base metal. Too high of a travel speed can result in over-running of the weld pool and an uncontrollable arc. Fusion between the base metal and filler metal can completely stop if the travel rate is too fast. If the travel rate is too slow and if the weld pool size increases excessively, it can also restrict fusion to the base plate.

ELECTRODE EXTENSION

The **electrode extension (stickout)** is the distance from the contact tube to the arc measured along the wire. Adjustments in this distance cause a change in the wire resistance and the resulting weld bead, **Figure 10-17**.

GMA welding currents are relatively high for the wire sizes, even for the low current values used in short-circuiting arc metal transfer, **Figure 10-18**. As the length of wire extending from the contact tube to the work increases, the voltage should also increase. Because this change is impossible with a constant-voltage power supply, the system compensates by reducing the current. In other words, by increasing the electrode extension and maintaining the same wire-feed speed, the current has to change to provide the same resistance drop. This situation leads to a reduction in weld heat, penetration, and fusion, and an increase in buildup. However, as the electrode extension distance is shortened, the weld heats up, penetrates more, and builds up less, **Figure 10-19**.

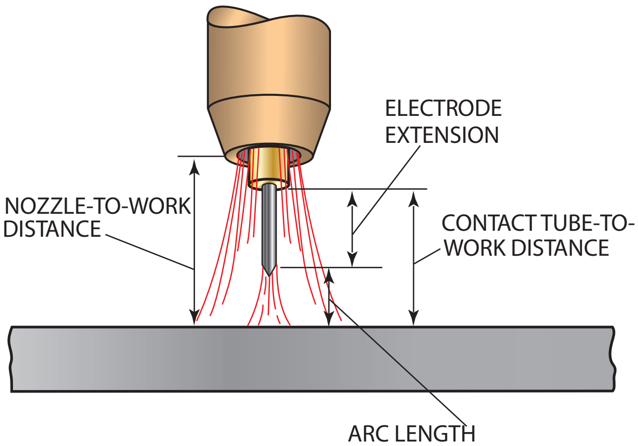


FIGURE 10-17 Electrode-to-work distances.

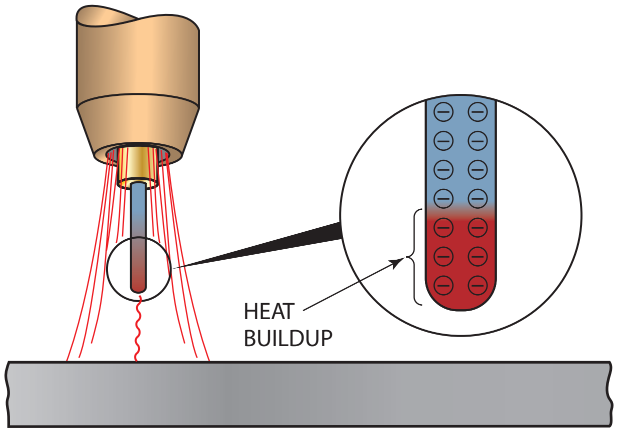


FIGURE 10-18 Heat buildup due to the extremely high current for the small conductor (electrode).

Experiment 11-4 explains the technique of using varying extension lengths to change the weld characteristics. Using this technique, a welder can make acceptable welds on metal ranging in thickness from 16 gauge to 1/4 in. (6 mm) or more without changing the machine settings. When using this technique, the nozzle-to-work distance should be kept the same so that enough shielding gas coverage is provided. Some nozzles can be extended to provide coverage. Others must be exchanged with the correct-length nozzle, **Figure 10-20**.

GUN ANGLE

The *gun angle*, *work angle*, and *travel angle* are names used to refer to the relation of the gun to the work surface. The gun angle can be used to control the weld pool. The electric arc produces an electrical force known as the arc force. The

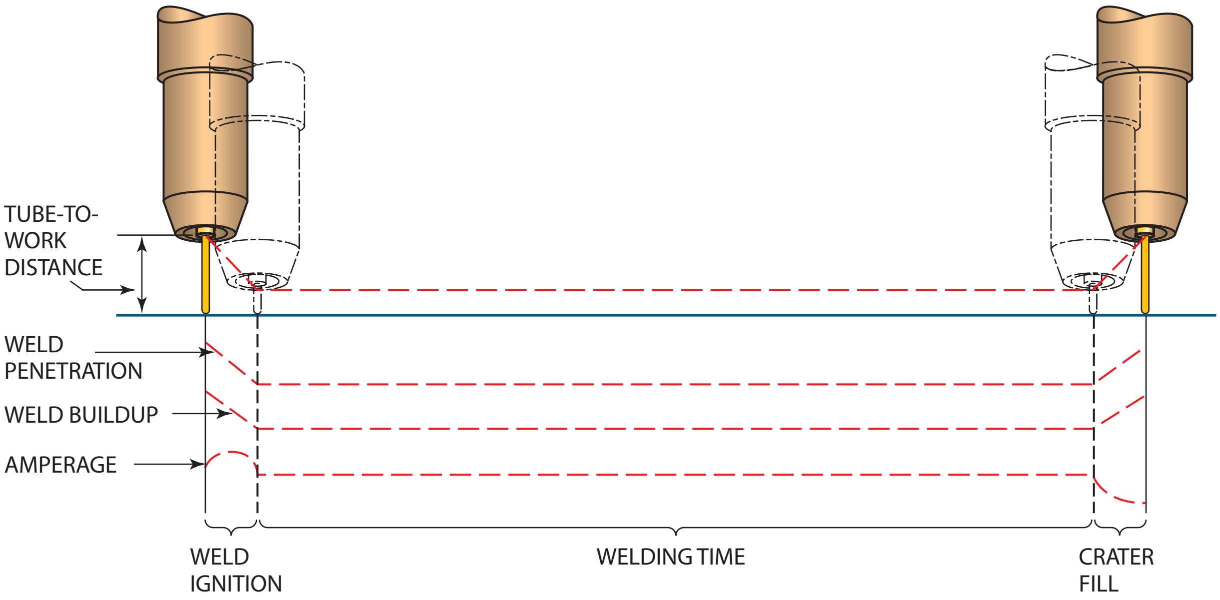


FIGURE 10-19 Using the changing tube-to-work distance to improve both the starting and stopping points of a weld.

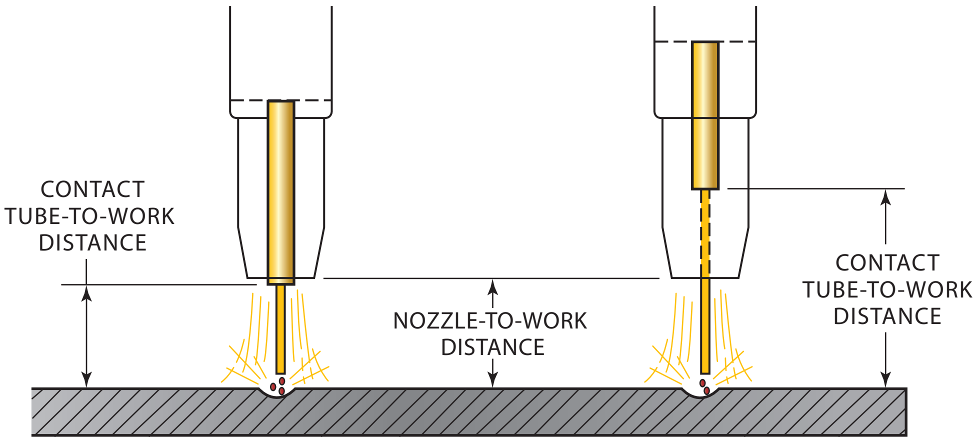


FIGURE 10-20 Nozzle-to-work distance can differ from the contact tube-to-work distance.

arc force can be used to counteract the gravitational pull that tends to make the liquid weld pool sag or run ahead of the arc. By manipulating the electrode travel angle for the flat and horizontal position of welding to a 20° to 90° angle from the vertical, the weld pool can be controlled. A 40° to 50° angle from the vertical plate is recommended for fillet welds.

Changes in this angle will affect the weld bead shape and penetration. Shallower angles are needed when welding thinner materials to prevent burnthrough. Steeper, perpendicular angles are used for thicker materials.

Forehand/Perpendicular/Backhand Welding

Forehand, *perpendicular*, and *backhand* are the terms most often used to describe the gun angle as it relates to the work and the direction of travel. The forehand technique is sometimes referred to as pushing the weld bead, **Figure 10-21A**, and backhand may be referred to as pulling or dragging the weld bead, **Figure 10-21C**. The term *perpendicular* is used when the gun angle is at approximately 90° to the work surface, **Figure 10-21B**.

Forehand welding has good joint visibility and makes welds with less joint penetration; this technique works well on vertical up and overhead welds, **Figure 10-22**.

Perpendicular welding has a good balance between penetration and reinforcement and is used on automated welding.

Backhand welding has good bead visibility and makes welds with deeper joint penetration, **Figure 10-23**.

The greater the angle, the more defined is the effect on the weld. As the angle approaches vertical, the effect is reduced. This allows the welder to change the weld bead as effectively as the changes resulting from adjusting the machine current settings.

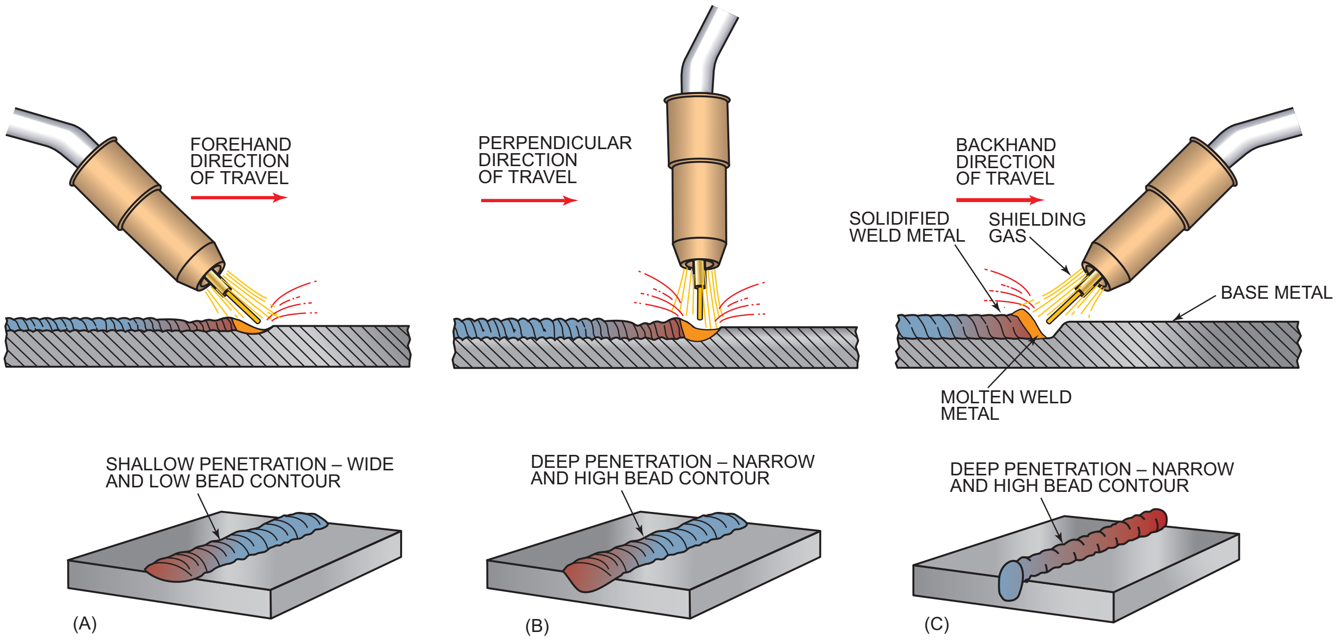


FIGURE 10-21 (A) Forehand welding or push angle, (B) perpendicular, and (C) backhand welding or drag angle.

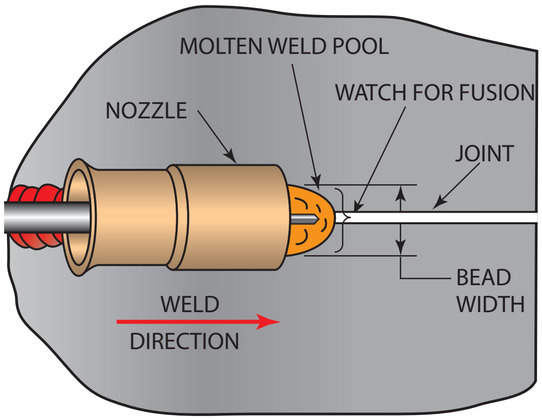


FIGURE 10-22 Forehand weld joint visibility.

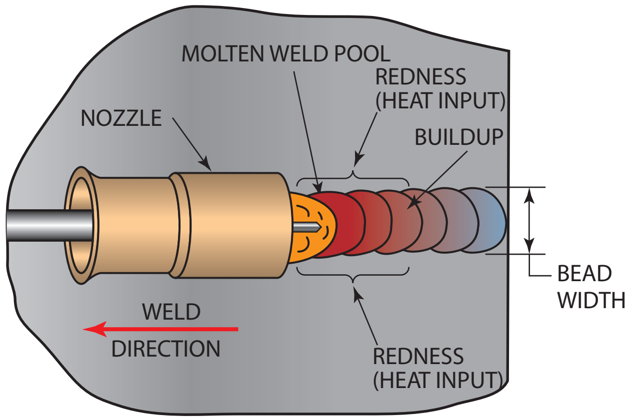


FIGURE 10-23 Backhand weld visibility.

METAL CORE ELECTRODES FOR GMA WELDING

Metal core electrodes are made much like the tubular electrodes used in flux cored arc welding. These welding electrodes combine the best parts of FCAW and GMAW. The major difference is that metal cored arc welding electrodes only have 1% to 2% of nonmetallic fluxing agents and shielding gas formers as compared to FCA welding electrodes that can have up to 15% of nonmetallic material in its core. The lower percentage of nonmetallic compounds results in less slag, less postweld cleanup, and less smoke in the welding shop. There are enough fluxing agents to prevent porosity when making welds that have light surface rust or mill scale. The flux also helps with joint penetration and fusion.

The addition of the powdered metal in the core increases buildup for higher welding speeds and adds to the arc stability, resulting in a smoother arc with a reduction in spatter. Metal core electrodes can be used in any position and on joints that have larger or uneven root openings.

There are no changes in equipment and very little change in setup to change from solid wire GMA to metal core GMA welding. Metal core wire can be used with any of the metal transfer methods in any position. It does require the use of a shielding gas with at least 75% argon. The higher deposition rates and reduced postweld cleanup can significantly offset the higher cost of the filler wire and more expensive argon CO_2 gas mixture.

The metal core electrode's smoothness allows it to be used on thin sheet metal without melt-through with low

amperage setting, and on higher amperage settings deep penetration in thick plate sections is achieved.

The ability to place different powered metal alloys in the core has allowed manufacturers to provide the welding industry with a wide range of new electrodes to meet most needs. For an electrode manufacturer to change the alloys of a solid wire they must have a steel manufacturer create an ingot that contains the desired alloys. The ingot would then have to be processed into the finished solid wire. But with metal cored wires, almost any powered metal alloy can be obtained, blended with other powdered metals, and placed inside the hollow tube that will become the electrode.

EQUIPMENT

The basic GMAW equipment consists of the gun, electrode (wire) feed unit, electrode (wire) supply, power source, shielding gas supply with flowmeter/regulator, control circuit, and related hoses, liners, and cables, **Figure 10-24** and **Figure 10-25**. Larger, more complex systems may have water for cooling, solenoids for controlling gas flow,

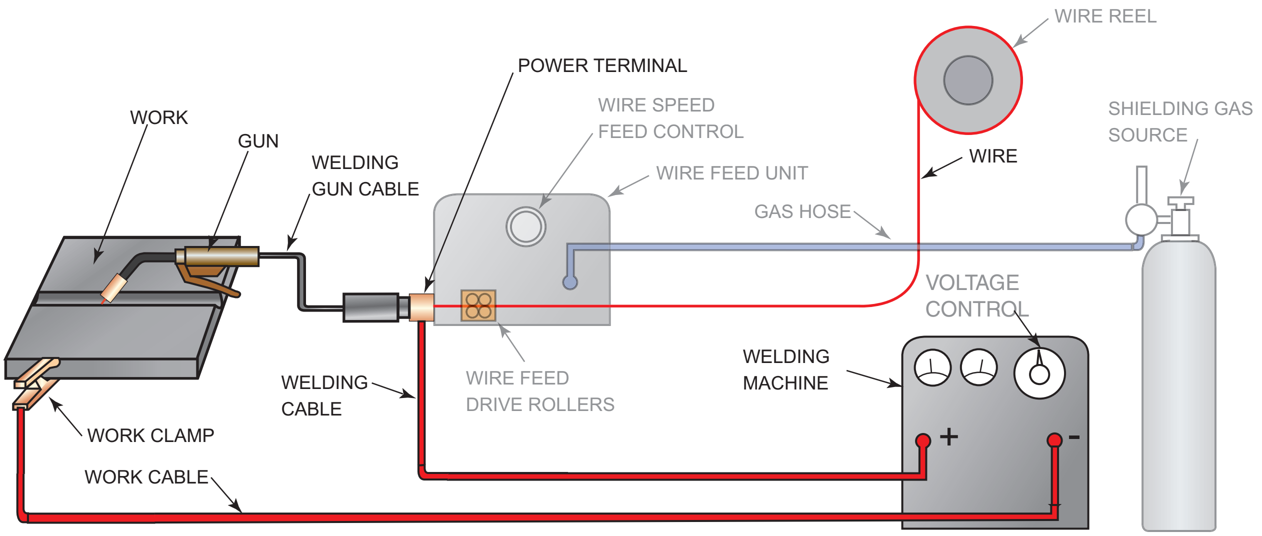


FIGURE 10-24 Schematic of equipment setup for GMA welding.

FIGURE 10-25 Small 110V GMA welder.

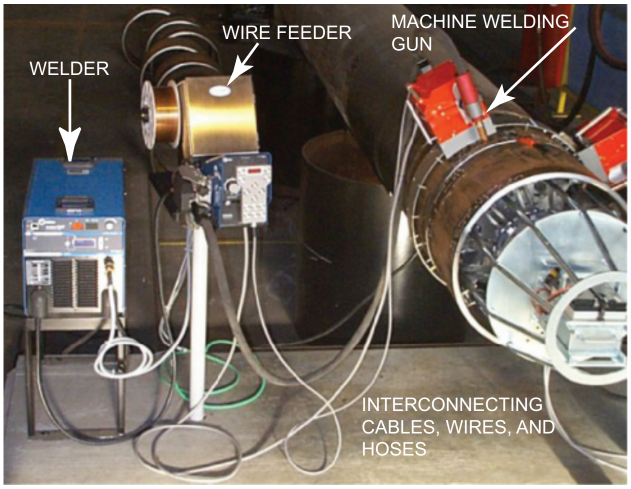


FIGURE 10-26 Typical interconnecting cables and wires for a semiautomatic GMA welding station.

and carriages for moving the work or the gun or both, **Figure 10-26**. The system may be stationary or portable. In most cases, the system is meant to be used for only one process. Some manufacturers, however, do make power sources that can be switched over for other uses.

Power Source

The power source may be either a transformer-rectifier or generator type. The transformers are stationary and commonly require a three-phase power source. Engine generators are ideal for portable use or where sufficient power is not available.

The welding machine produces a DC welding current ranging from 40 amperes to 600 amperes with 10 volts to 40 volts, depending on the machine. In the past, some GMA processes used AC welding current, but DCRP is used almost exclusively now. Typical power supplies are shown in **Figure 10-27**.

Because of the long periods of continuous use, GMA welding machines have a 100% duty cycle. This allows the machine to be run continuously without damage.

Electrode (Wire) Feed Unit

The purpose of the electrode feeder is to provide a steady and reliable supply of wire to the weld. Slight changes in the rate at which the wire is fed have distinct effects on the weld.

The motor used in a feed unit is usually a DC type that can be continuously adjusted over the desired range. **Figure 10-28** and **Figure 10-29** show typical wire-feed units and accessories.

Push-Type Feed System The wire rollers are clamped securely against the wire to provide the necessary friction to push the wire through the conduit to the gun. The pressure applied on the wire can be adjusted. A groove is provided in the roller to aid in alignment and to lessen the chance of slippage. Most manufacturers provide rollers with smooth or knurled U-shaped or V-shaped grooves, **Figure 10-30**. Knurling

(A)

(B)

FIGURE 10-27 An expensive 200-ampere constant-voltage power supply (A) and a 650-ampere constant-voltage and constant-current power supply (B) for multipurpose GMAW applications.

Courtesy of Lincoln Electric Company

(A)

Courtesy of ESAB Welding & Cutting Products

(B)

FIGURE 10-28 (A) A 90-ampere power supply and wire feeder for welding sheet steel with carbon dioxide shielding. (B) Modern wire feeder with digital preset and readout of wire-feed speed and closed-loop control.

(a series of ridges cut into the groove) helps grip larger diameter wires so that they can be pushed along more easily. Soft wires, such as aluminum, are easy to damage if knurled rollers are used. Soft wires are best used with U-grooved rollers. Even V-grooved rollers can distort the surface of the wire, causing problems. V-grooved rollers are best suited for hard wires, such as mild steel and stainless steel. It is also important to use the correct-size grooves in the rollers.

Variations of the push-type electrode wire feeder include the pull type and push-pull type. The difference is in the size and location of the drive rollers. In the push-type system, the electrode must have enough strength to be pushed through the conduit without kinking. Mild steel and stainless steel can be readily pushed 15 ft (4 m) to 20 ft (6 m), but aluminum is much harder to push more than 10 ft (3 m).

Pull-Type Feed System In pull-type systems, a smaller but higher-speed motor is located in the gun to pull the wire through the conduit. Using this system, it is possible to move even soft wire over great distances. The disadvantages are that the gun is heavier and more difficult to use, rethreading the wire takes more time, and the operating life of the motor is shorter. Because of improvements in push-type wire feed systems, pull-type wire feed systems are not commonly used anymore.

Push-Pull–Type Feed System Push-pull feed systems use a synchronized system with feed motors located at both ends of the electrode conduit, **Figure 10-31**. This system can be used to move any type of wire over long distances by periodically installing a feed roller into the electrode conduit. Compared to the pull-type system, the advantages of this system include the ability to move wire over longer distances, faster rethreading, and increased motor life due to the reduced load. A disadvantage is that the system is more expensive.

Linear Electrode Feed System Linear electrode feed systems use a different method to move the wire and change the feed speed. Standard systems use rollers that pinch the wire between the rollers. A system of gears is used between the motor and rollers to provide roller speed within the desired range. The linear feed system does not have gears or conventional-type rollers.

The linear feed system uses a small motor with a hollow armature shaft through which the wire is fed. The rollers are attached so that they move around the wire. Changing the roller pitch (angle) changes the speed at which the wire is moved without changing the motor speed. This system works in the same way that changing the pitch on a screw, either coarse threads or fine threads, affects the rate that the screw will move through a spinning nut.

The advantage of a linear system is that the bulky system of gears is eliminated, thus reducing weight, size, and wasted power. The motor operates at a constant high speed at which it is more efficient. The reduced size allows the system to be housed in the gun or within an enclosure in the cable. Several linear wire feeders can be synchronized to provide an extended operating range. The disadvantage of a linear system is that the wire may become twisted as it is moved through the feeder.

Spool Gun A spool gun is a compact, self-contained system consisting of a small drive system and a wire supply, **Figure 10-32**. This system allows the welder to move freely around a job with only a power lead and shielding gas hose to manage. The major control system is usually mounted

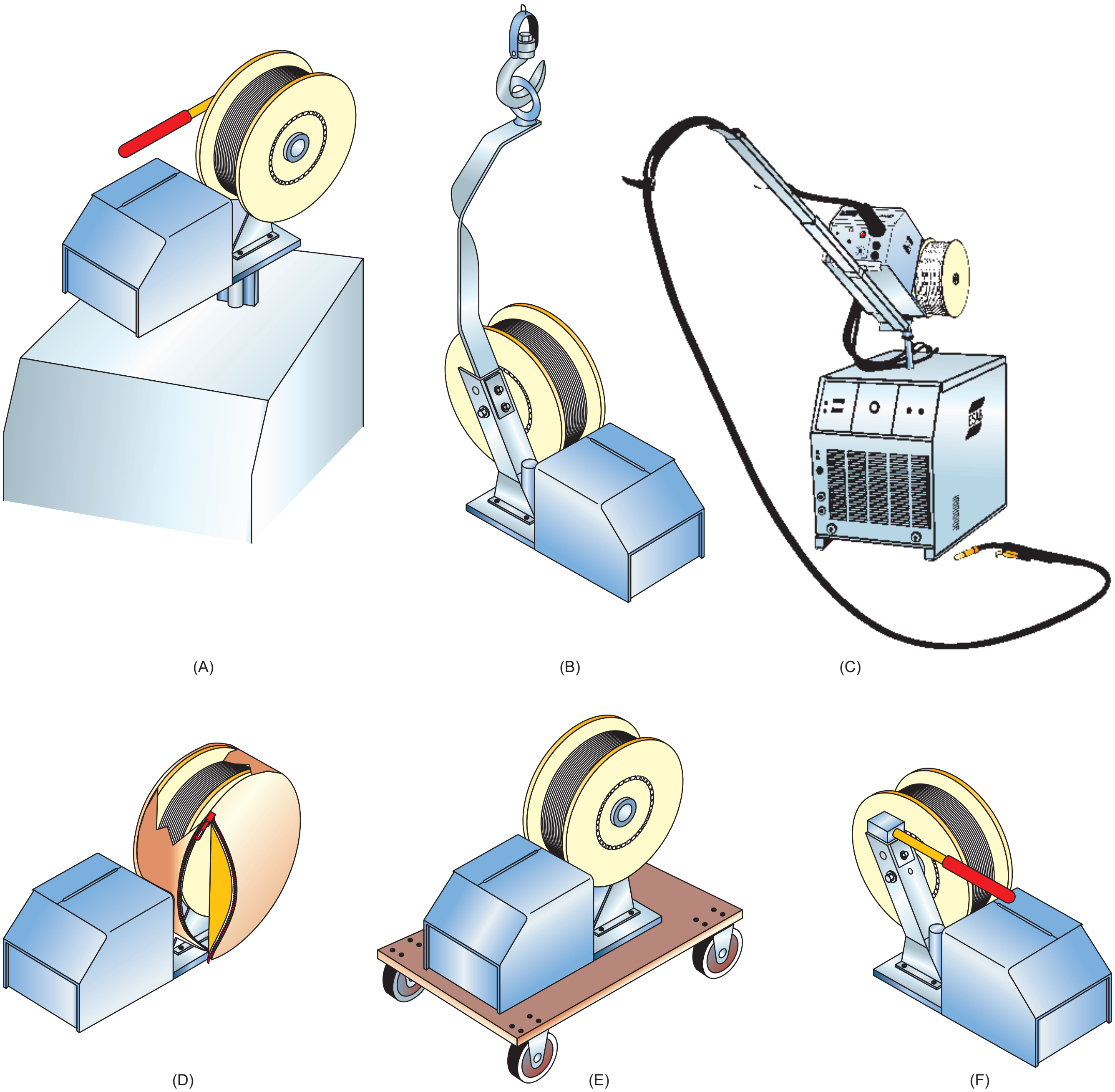


FIGURE 10-29 A variety of accessories is available for most electrode feed systems: (A) swivel post, (B) boom hanging bracket, (C) counterbalance mini-boom, (D) spool cover, (E) wire-feeder wheel cart, and (F) carrying handle.

on the welder. The feed rollers and motor are found in the gun just behind the nozzle and contact tube. Because of the short distance that the wire must be moved, very soft wires (aluminum) can be used. A small spool of welding wire is located just behind the feed rollers. The small spools of wire required in these guns are often very expensive. Although the guns are small, they feel heavy when being used.

Electrode Conduit

The electrode conduit or liner guides the welding wire from the feed rollers to the gun. It may be encased in a lead that contains the shielding gas.

Power cable and gun switch circuit wires are contained in a conduit that is made of a tightly wound coil with the needed flexibility and strength. The steel conduit may have a nylon or Teflon liner to protect soft, easily scratched metals, such as aluminum, as they are fed.

If the conduit is not an integral part of the lead, it must be firmly attached to both ends of the lead. Failure to attach the conduit can result in misalignment, which causes additional drag or makes the wire jam completely. If the conduit does not extend through the lead casing to make a connection, it can be drawn out by tightly coiling the lead, **Figure 10-33**. Coiling will force the conduit out so that it can be connected.

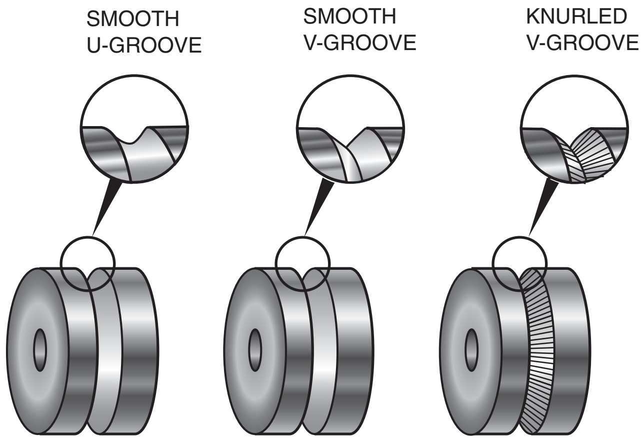


FIGURE 10-30 Feed rollers.

Courtesy of Lincoln Electric Company

FIGURE 10-31 Wire-feed system that enables the wire to be moved through a longer cable.

Courtesy of ESAB Welding & Cutting Products

FIGURE 10-32 Feeder/gun for GMA welding.

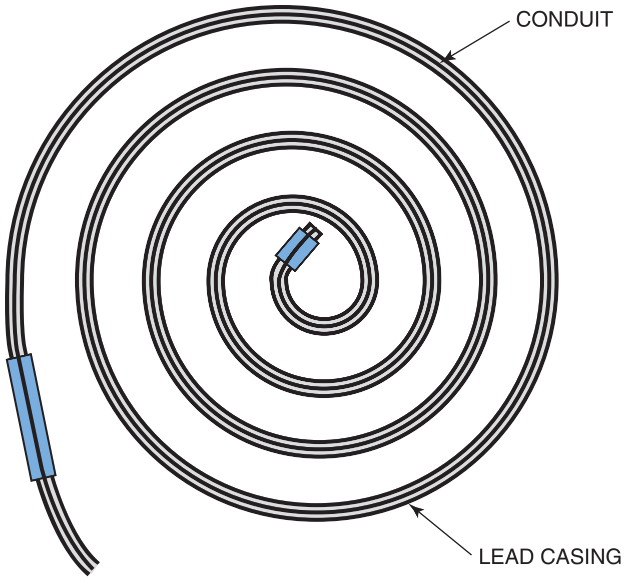


FIGURE 10-33 Tightly coiled lead casing will force the liner out of the gun.

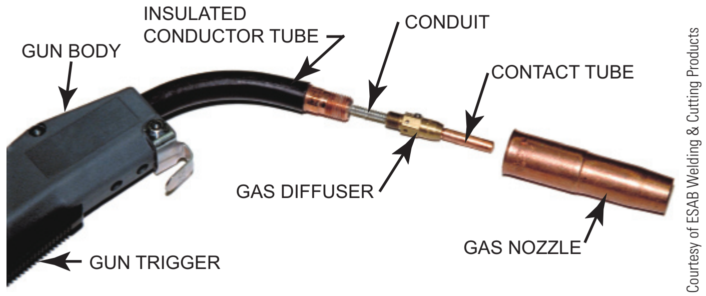
If the conduit is too long for the lead, it should be cut off and filed smooth. Too long a lead will bend and twist inside the conduit, which may cause feed problems.

Welding Gun

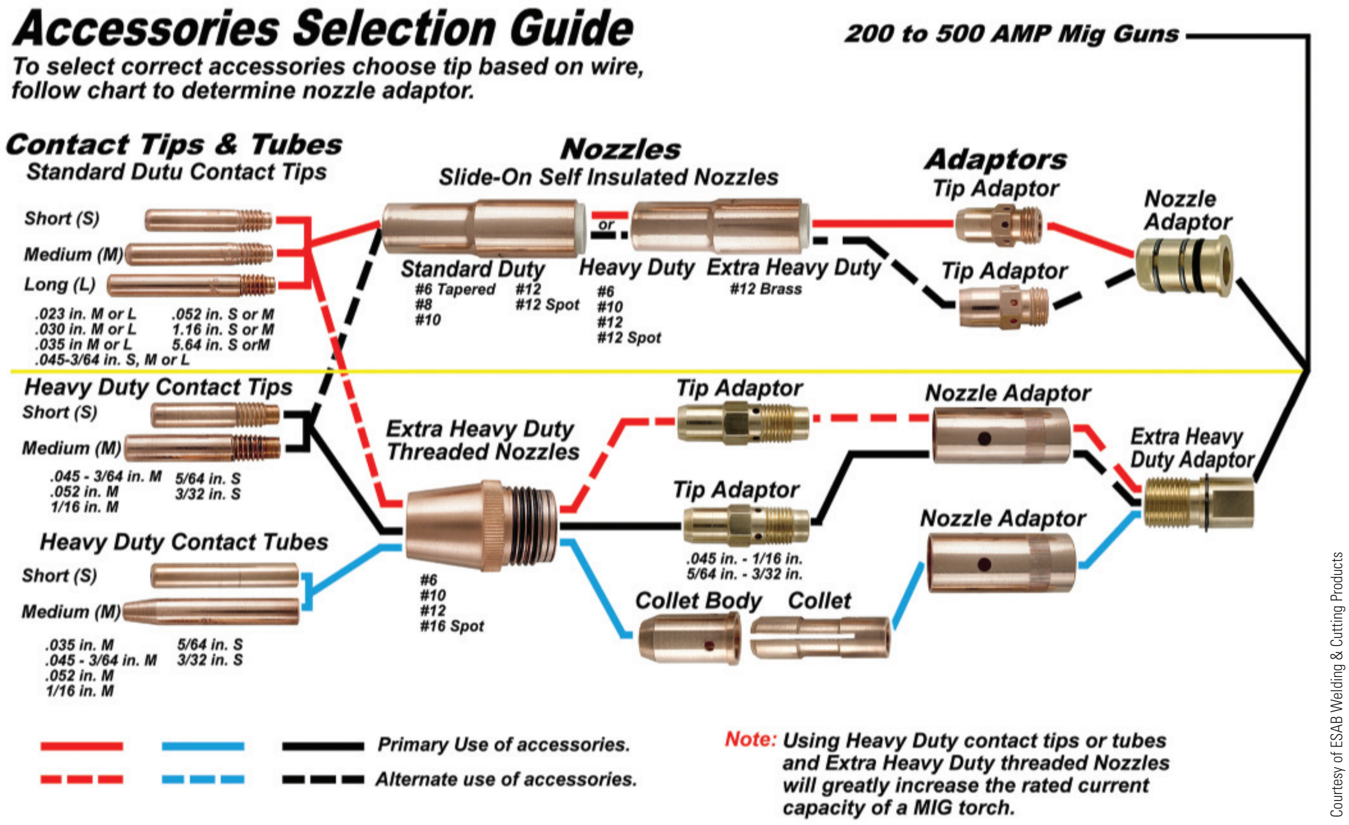
The welding gun attaches to the end of the power cable, electrode conduit, and shielding gas hose, **Figure 10-34**. It is used by the welder to produce the weld. A trigger switch is used to start and stop the weld cycle. The gun also has a contact tube, which is used to transfer the welding current to the electrode

Courtesy of ESAB Welding & Cutting Products

FIGURE 10-34 A typical GMA welding gun used for most welding processes with a heat shield attached to protect the welder's gloved hand from intense heat generated when welding with high amperages.



(A)



(B)

FIGURE 10-35 (A) Typical replaceable parts of a GMA welding gun. (B) Accessories and parts selection guide for a GMA welding gun.

moving through the gun, and a gas nozzle, which directs the shielding gas onto the weld, **Figure 10-35**.

GMA SPOT WELDING

GMA can be used to make high-quality arc spot welds. Welds can be made using standard or specialized equipment. The arc spot weld produced by GMAW differs from electric resistance spot welding. The GMAW spot weld starts on one surface of one member and burns through to the other member, **Figure 10-36**. Fusion between the members occurs, and a small nugget is left on the metal surface.

GMA spot welding has some advantages such as the following: (1) welds can be made in thin-to-thick materials; (2) the weld can be made when only one side of the materials to be welded is accessible; and (3) the weld can be made when there is paint on the interfacing surfaces. The arc spot weld can also be used to assemble parts for welding to be done at a later time.

Thin metal can be attached to thicker sections using an arc spot weld. If a thin-to-thick butt, lap, or tee joint is to be welded with complete joint penetration, often the thin material will burn back, leaving a hole, or there will not be enough heat to melt the thick section. With an arc spot weld, the burning back of the thin material allows the thicker metal to be melted. As more metal is added to the weld, the burnthrough is filled, Figure 10-36.

The GMA spot weld is produced from only one side. Therefore, it can be used on awkward shapes and in

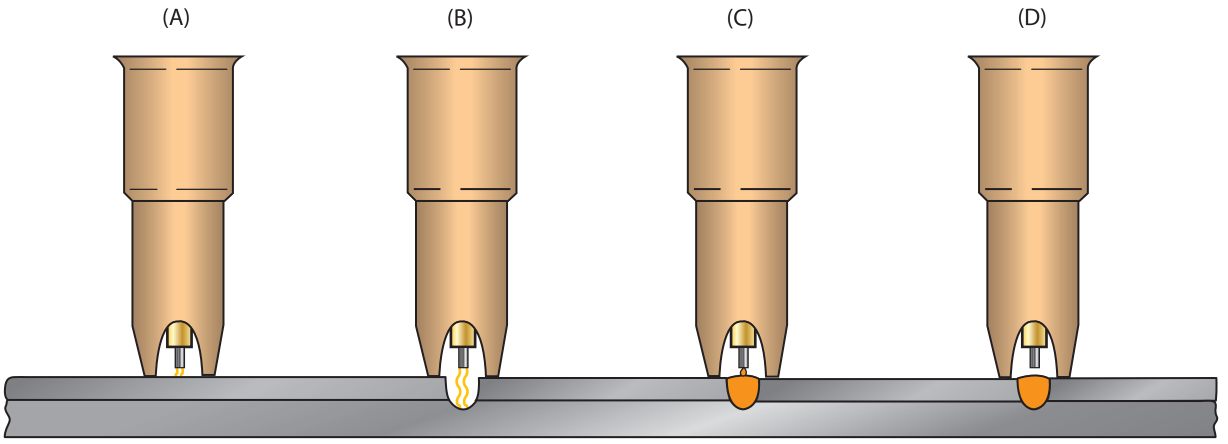


FIGURE 10-36 GMA spot weld: (A) the arc starts, (B) a hole is burned through the first plate, (C) the hole is filled with weld metal, and (D) the wire feed stops and the arc burns the electrode back.

cases where the other side of the surface being welded should not be damaged. This makes it an excellent process for auto body repair. In addition, because the metals are melted and the molten weld pool is agitated, thin films of paint between the members being joined need not be removed. This is an added benefit for auto body repair work.

CAUTION

Safety glasses and/or flash glasses must be worn to protect the eyes from flying sparks.

Specially designed nozzles provide flash protection, part alignment, and arc alignment, **Figure 10-37**. As a result, for some small jobs it may be possible to perform the weld with only safety glasses. Welders can shut their eyes and turn their head during the weld.

The optional control timer provides weld time and burn-back time. To make a weld, the amperage, voltage, and length of welding time must be set correctly. The burn-back time is a short period at the end of the weld when the wire feed stops but the current does not. This allows the wire to be burned back so it does not stick in the weld, Figure 10-36.

CAUTION

This is not advisable for any work requiring more than just a few spot welds. Prolonged exposure to the reflected ultraviolet light will cause skin burns.

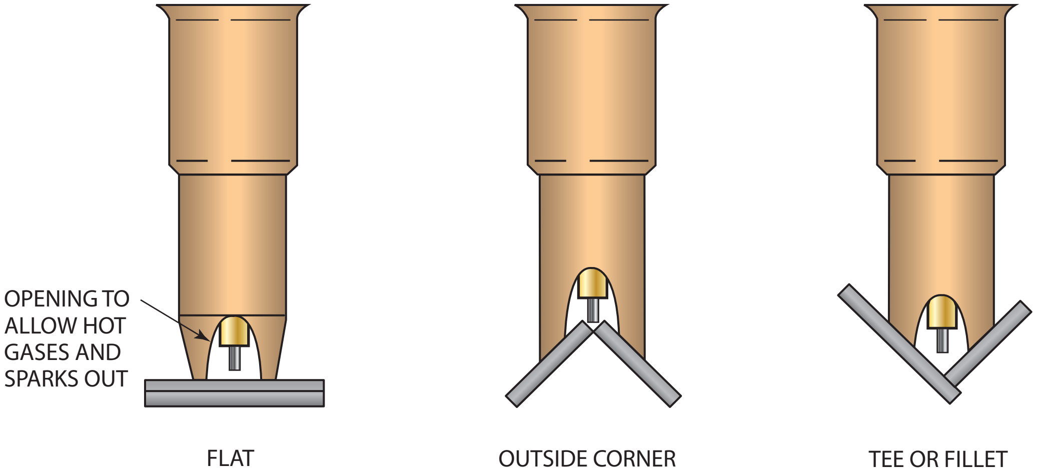


FIGURE 10-37 Specialized nozzles for GMA spot welding.

Summary

The keys to producing quality GMA welds are equipment, setup, and adjustments. Once you have mastered these skills, the only remaining obstacle to your producing consistent, uniform, high-quality welds is your ability to follow, or track, the joint consistently. Some welders find that lightly dragging their glove along the metal surface or edge of the fabrication can aid them in controlling the weld consistency. One of the various advantages of the GMA welding process is its ability to produce long, uninterrupted welds. However, this often leads to welder fatigue. Finding a comfortable welding position that you can maintain for several minutes at a time will improve your weld quality and reduce your fatigue.

Selecting the proper method of metal transfer—short arc, globular, or axial spray—is normally done by the welding shop foreman or supervisor. He or she makes these selections based on the material being welded, the welding position, and other such factors. A welder must be proficient with each of the various methods of metal transfer. Therefore, it is important that you spend time practicing and developing your skills with each of these processes.

Review

1. Why is usage of the term *GMAW* preferable to *MIG* for gas metal arc welding?
2. Using Table 10-1, answer the following:
   a. What maintains the arc in machine welding?
   b. What feeds the filler metal in manual welding?
   c. What provides the joint travel in automatic welding?
   d. What provides the joint guidance in semiautomatic welding?
3. What factors must be considered when selecting which mode of metal transfer to use?
4. In short-circuiting transfer, what type of current allows the liquid metal at the electrode tip to be transferred by direct contact with the molten weld pool?
5. Describe the globular transfer process.
6. In what form is metal transferred across the arc in the axial spray metal transfer method of GMA welding?
7. What three conditions are required for the spray transfer process to occur?
8. Using Table 10-3, answer the following:
   a. What should the wire-feed speed and voltage ranges be to weld 1/8-in. (3 mm) metal with 0.035-in. (0.90-mm) wire using argon shielding gas?
   b. What should the amperage and voltage range be using 98% Ar + 2% O_2 to weld 1/4-in. (6-mm) metal with 0.045-in. (1.2-mm) wire?
9. Describe the current produced by the pulsed-arc metal transfer mode.
10. In the pulsed-arc metal transfer current cycle, what is the term used to describe how the electric current in a transformer takes a few milliseconds to build up the magnetic field to full strength once the coil is energized?
11. List five advantages of the modulated current and pulsed-arc metal transfer process.
12. What is the difference between the wire melting rate and the deposition rate?
13. Using Figure 10-13, what is the approximate voltage at 175 amps at 200 in./min?
14. Using Table 10-6, what would the amperage be for 0.035-in. (0.9-mm) wire at 200 in./min (5 m/min)?
15. The shielding gas selected can affect what properties of a weld?
16. What may happen if the GMA welding electrode is allowed to strike the base metal outside of the molten weld pool?
17. What effect does shortening the electrode extension have on weld penetration?
18. Describe the weld produced by a forehand welding angle.
19. Describe the weld produced by a backhand welding angle.
20. What components make up a GMA welding system?
21. Why must GMA welders have a 100% duty cycle?
22. What can happen if rollers of the wrong shape are used on aluminum wire?
23. Where is the drive motor located in a pull-type wire-feed system?
24. How is the wire-feed speed changed with a linear feed system?
25. What type of liner should be used for aluminum wire?
26. What parts of a typical GMA welding gun can be replaced?
27. Describe the spot welding process using a GMA welder.

Chapter 11

Gas Metal Arc Welding

OBJECTIVES

After completing this chapter, the student should be able to

- demonstrate how to properly set up a GMA welding installation.
- demonstrate how to thread the electrode wire on a GMAW machine.
- demonstrate how to set the shielding gas flow rate on a GMAW machine.
- use various settings on a GMA welding machine and compare the effects on a weld.
- show the effect of changing the electrode extension on a weld.
- describe the effects of changing the welding gun angle on the weld bead.
- tell what must be considered when selecting the right shielding gas for a particular application.
- evaluate weld beads made with various shielding gas mixtures.
- tell why hot-rolled steel should be cleaned to bright metal before welding.
- demonstrate how to properly make GMA welds in butt joints, lap joints, and tee joints in all positions that can pass the specified standard.

KEY TERMS

bird-nesting

cast

conduit liner

contact tube

feed rollers

flow rate

spool drag

wire-feed speed

INTRODUCTION

Performing a satisfactory GMA weld requires more than just manipulative skill. The setup, voltage, amperage, electrode extension, and welding angle, as well as other factors, can dramatically affect the weld produced. The very best welding conditions are those that will allow a welder to produce the largest quantity of successful welds in the shortest period of time with the highest productivity. Because these are semi-automatic or automatic processes, increased productivity may only require the welder to increase the travel speed and current. This does not mean that the welder will work harder, but rather that the welder will work more productively, resulting in greater cost efficiency.

The more cost-efficient welders can be, the more competitive they and their companies become. This can make the difference between being awarded a bid or a job and having or losing work.

Courtesy of Lincoln Electric Company

FIGURE 11-1 Combination GMA and FCA welding system.

Courtesy of ESAB Welding & Cutting Products

FIGURE 11-2 GMA welding guns are available in a variety of sizes and shapes. Note that the gun necks range from straight up to nearly a 90-degree angle.

SETUP

The same equipment may be used for semiautomatic GMAW, FCAW, and SAW. Except for the fact that all GMA welding requires a shielding gas so the equipment must have a shielding gas solenoid and some types of FCA welding, filler wires can be used without a shielding so no solenoid would be required and the power supplies are the same. The solenoid is used to start and stop the shielding gas at the same time as the power is switched on and off. Some welding power supplies may have two separate wire-feed systems so that a welder can easily switch from GMA welding to FCA welding with the flip of a switch, **Figure 11-1**.

The basic GMAW installation consists of the following: welding gun, gun switch circuit, electrode conduit-welding contactor control, electrode feed unit, electrode supply, power source, shielding gas supply, shielding gas flowmeter regulator, shielding gas hoses, and both power and work cables. Typical water-cooled and air-cooled guns are shown in **Figure 11-2**. The equipment setup in this chapter is similar to equipment built by other manufacturers, which means that any skills developed can be transferred easily to other equipment.

PRACTICE 11-1

GMAW Equipment Setup

For this practice, you will need a GMAW power source, a welding gun, an electrode feed unit, an electrode supply, a shielding gas supply, a shielding gas flowmeter regulator, electrode conduit, power and work leads, shielding gas hoses, assorted hand tools, spare parts, and any other required materials. In this practice, you will properly set up a GMA welding installation.

If the shielding gas supply is a cylinder, then it must be chained securely in place before the valve protection cap is removed, **Figure 11-3**. Standing to one side of the cylinder, quickly crack the valve to blow out any dirt in the valve before the flowmeter regulator is attached, **Figure 11-4**. With the flowmeter regulator attached securely to the cylinder valve, attach the correct hose from the flowmeter to the "gas-in" connection on the electrode feed unit or machine.

Install the reel of electrode (welding wire) on the holder and secure it, **Figure 11-5**. Check the feed roller size to ensure that it matches the wire size, **Figure 11-6**. The conduit liner size should be checked to be sure that it is compatible

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FIGURE 11-3 Make sure the gas cylinder is chained securely in place before removing the safety cap.

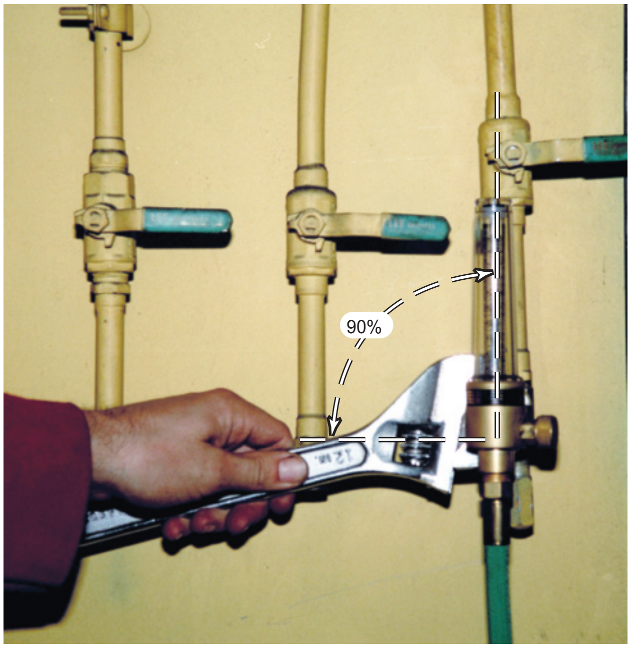

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FIGURE 11-4 Attach the flowmeter regulator. Be sure the tube is vertical.

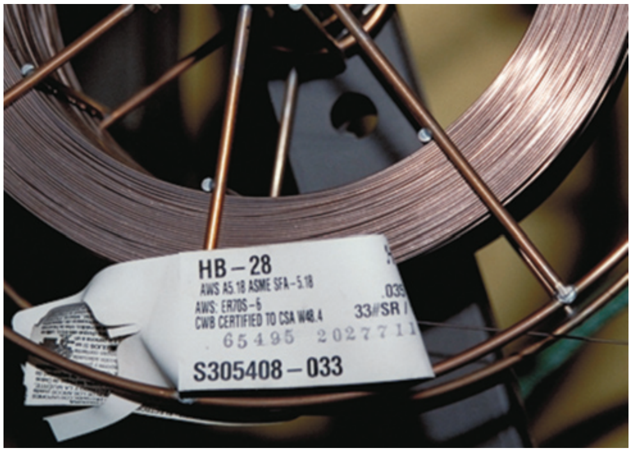

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FIGURE 11-5 When installing the spool of wire, check the label to be sure that the wire is the correct type and size.

with the wire size. Connect the conduit to the feed unit. The conduit or an extension should be aligned with the groove in the roller and set as close to the roller as possible without touching, **Figure 11-7**. Misalignment at this point can contribute to a bird's nest, **Figure 11-8**. **Bird-nesting** of the electrode wire results when the **feed roller** pushes the wire into a tangled ball because the wire would not go through the outfeed side conduit and appears to look like a bird's nest.

Be sure the power is off before attaching the welding cables. The electrode and work leads should be attached to the proper terminals. The electrode lead should be attached to the terminal marked electrode or positive (+). If necessary, it is also attached to the power cable part of the gun lead. The work lead should be attached to work or negative (−).

The shielding "gas-out" side of the solenoid is then also attached to the gun lead. If a separate splice is required from

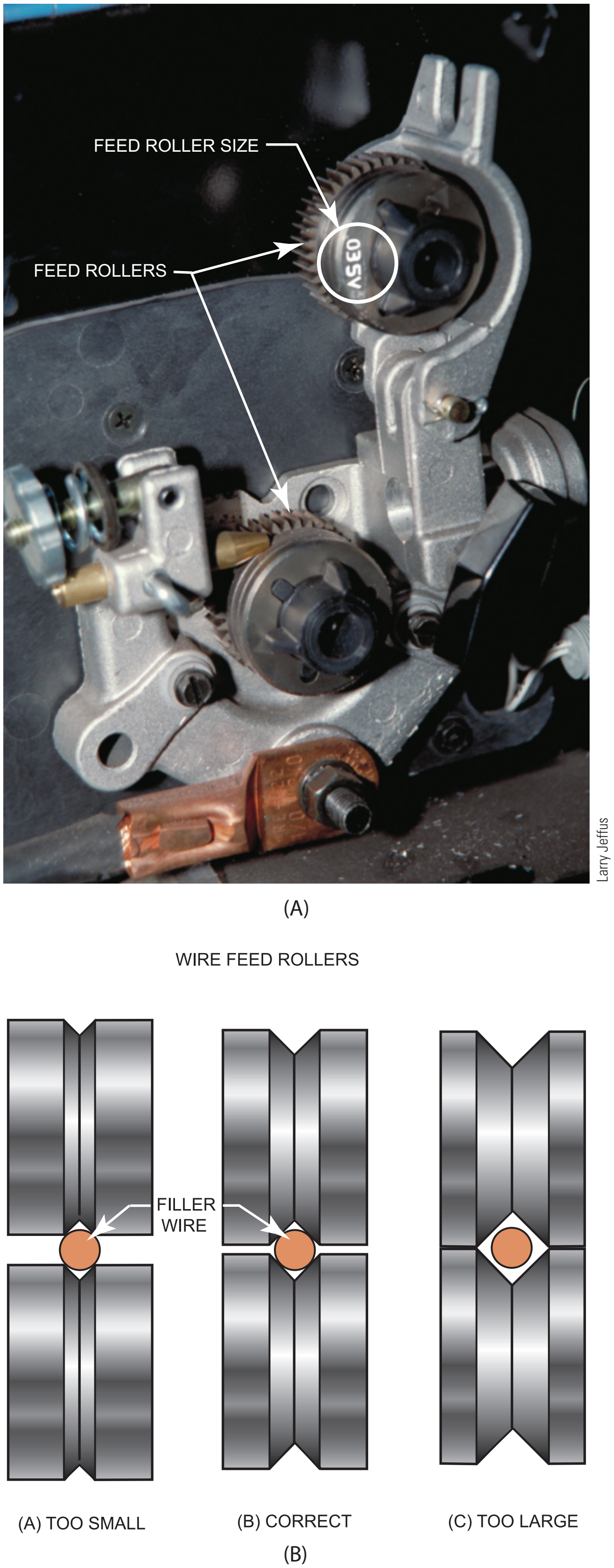

FIGURE 11-6 (A) Check to be certain that the feed rollers are the correct size for the wire being used. (B) If the wire-feed rollers are too small, the welding wire could be damaged. If the wire-feed rollers are too large, the rollers will not grip the wire.

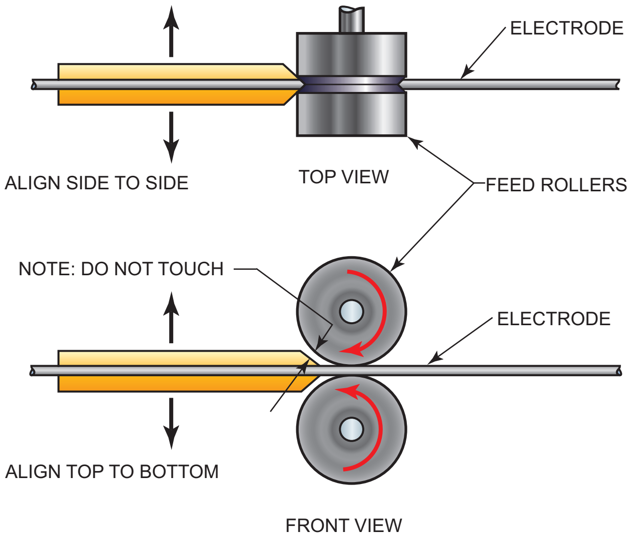

FIGURE 11-7 Feed roller and conduit alignment.

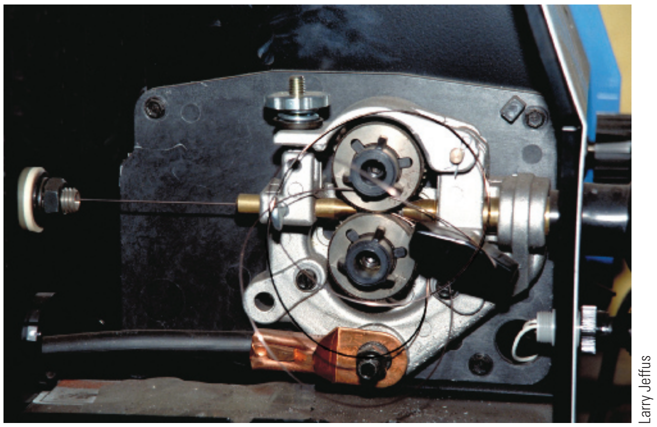

FIGURE 11-8 "Bird's nest" in the filler wire at the feed rollers.

the gun switch circuit to the feed unit, it should be connected at this time. Check to see that the welding contactor circuit is connected from the feed unit to the power source.

The welding gun should be securely attached to the main lead cable and conduit, **Figure 11-9**. There should be a gas diffuser attached to the end of the conduit liner to ensure proper alignment. A **contact tube** (tip) of the correct size to match the electrode wire size being used should be installed, **Figure 11-10**. A shielding gas nozzle is attached to complete the assembly.

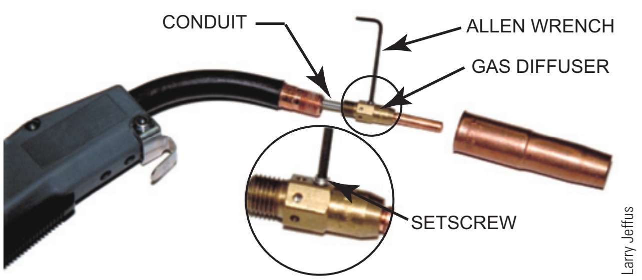

FIGURE 11-9 GMA welding gun assembly.

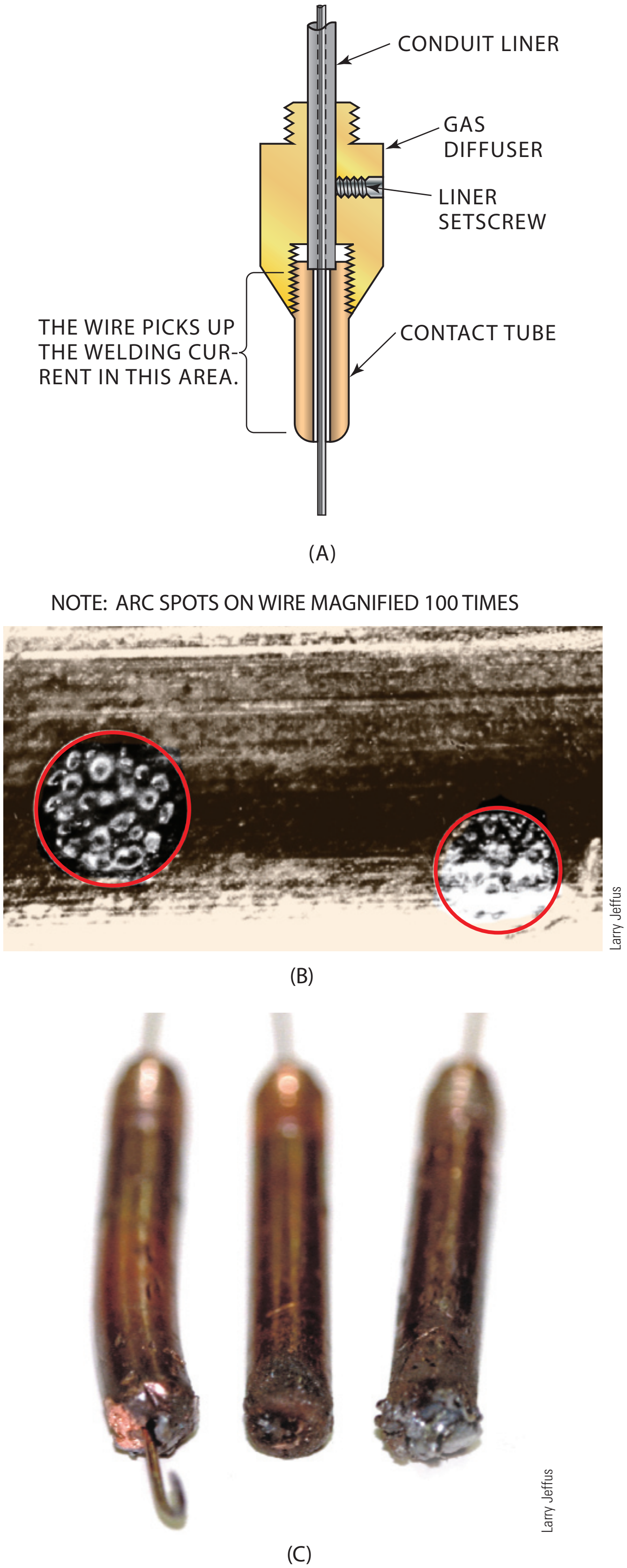

FIGURE 11-10 The contact tube must be the correct size. (A) Too small of a contact tube will cause the wire to stick. (B) Too large of a contact tube can cause arcing to occur between the wire and tube. (C) Heat from the arcing can damage the tube.

Recheck all fittings and connections for tightness. Loose fittings can leak; loose connections can cause added resistance, reducing the welding efficiency. Some manufacturers include detailed setup instructions with their equipment, **Figure 11-11.**

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 11-2

Threading GMAW Wire

Using the GMAW machine that was properly assembled in Practice 11-1, you will turn on the machine and thread the electrode wire through the system.

Check to see that the unit is assembled correctly according to the manufacturer's specifications. Switch on the power and check the gun switch circuit by depressing the switch. The power source relays, feed relays, gas solenoid, and feed motor should all activate.

Cut the end of the electrode wire free. Hold it tightly so that it does not unwind. The wire has a natural curve that is known as its **cast**. The cast is measured by the diameter of the circle that the wire would make if it were loosely laid on a flat surface. The cast helps the wire make a good electrical contact as it passes through the contact tube, **Figure 11-12**. However, the cast can be a problem when threading the system. To make threading easier, straighten approximately 12 in. (305 mm) of the end of the wire and cut any kinks off.

Separate the wire-feed rollers and push the wire first through the guides, then between the rollers, and finally into the **conduit liner**, **Figure 11-13**. Reset the rollers so there is a slight amount of compression on the wire, **Figure 11-14**. Set the **wire-feed speed** control to a slow speed. Hold the welding gun so that the electrode conduit and cable are as straight as possible.

Press the gun switch. The wire should start feeding into the liner. Watch to make certain that the wire feeds smoothly and release the gun switch as soon as the end comes through the contact tube.

CAUTION

If the wire stops feeding before it reaches the end of the contact tube, stop and check the system. If no obvious problem can be found, mark the wire with tape and remove it from the gun. It then can be held next to the system to determine the location of the problem.

With the wire-feed running, adjust the feed roller compression so that the wire reel can be stopped easily by a slight pressure. Too light of a roller pressure will cause the wire to feed erratically. Too high of a pressure can turn a minor problem into a major disaster. If the wire jams at a high roller pressure, the feed rollers keep feeding the wire, causing it to bird-nest and possibly short out. With a light pressure, the wire can stop, preventing bird-nesting. This is very important with soft wires such as aluminum; also, when welding with softer welding wires it is a good idea to use a wire conduit that has a Teflon® liner. The other advantage of a light pressure is that the feed will stop if something like clothing or gas hoses are caught in the reel.

With the feed running, adjust the **spool drag** so that the reel stops when the feed stops. The reel should not coast to a stop because the wire can be snagged easily. Also, when the feed restarts, a jolt occurs when the slack in the wire is taken up. This jolt can be enough to momentarily stop the wire, possibly causing a discontinuity in the weld.

When the test runs are completed, the wire can be either rewound or cut off. Some wire-feed units have a retract button. This allows the feed driver to reverse and retract the wire automatically. To rewind the wire on units without this retract feature, release the rollers and turn them backward by hand. If the machine will not allow the feed rollers to be released without upsetting the tension, you must cut the wire.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

CAUTION

Do not discard pieces of wire on the floor. They present a hazard to safe movement around the machine. In addition, a small piece of wire can work its way into a filter screen on the welding power source. If the piece of wire shorts out inside the machine, it could become charged with high voltage, which could cause injury or death. Always wind the wire tightly into a ball or cut it into short lengths before discarding it in the proper waste container.

WIRE-FEED SPEED

Because changes in the wire-feed speed automatically change the amperage, it is possible to set the amperage by using a chart and measuring the length of wire fed per minute, **Table 11-1**. The wire-feed speed is generally recommended by the electrode manufacturer and is selected in inches per minute (ipm), which can be measured by how fast the wire exits the contact tube. The welder uses a wire-feed speed control dial on the wire-feed unit to control the ipm.

The wire-feed speed is given in a range. The range allows you to adjust the feed speed according to the welding conditions. The wire speed control dial can be advanced or slowed to control the burn weld size and deposition rate.

EXPERIMENT 11-1

Setting Wire-Feed Speed

Using the equipment setup as described in Practice 11-1 and the threaded machine as described in Practice 11-2,

FIGURE 11-11 Example of manufacturer's setup instructions: (A) open the side cover; (B) remove the empty wire spool; (C) release upper feed roller; (D) reload the wire spool with the free end unreeling from the bottom; (E) thread wire through the guide between rollers and into wire cable; (F) set the polarity as DCEP from GMA welding; (G) turn the input switch on; (H) with the gun trigger pressed, adjust the feed roller tension; (I) check the setting guide inside the machine door; (J) set the voltage and wire feed for the metal you are going to be welding; (K) attach the work cable clamp to the work to be welded; (L) connect the gas to coupling at the rear of the case and turn on shielding gas; and (M) ALWAYS WEAR PROPER SAFETY EQUIPMENT. Pull trigger and weld.

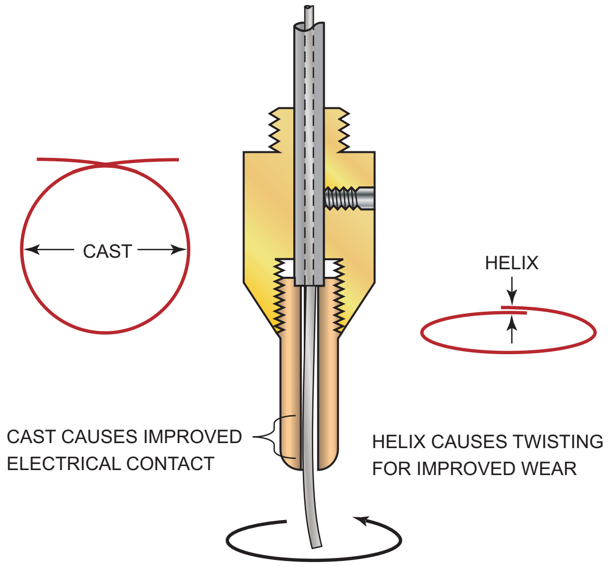

FIGURE 11-12 The cast of the welding wire causes it to rub firmly inside of the contact tube for good electrical contact. The helix causes the electrode to twist inside of the contact tube so that the tube is worn uniformly.

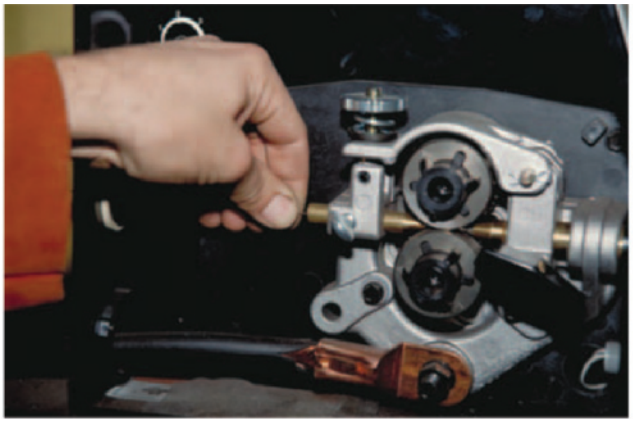

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FIGURE 11-13 Push the wire through the guides by hand.

you will set the wire-feed speed. At high wire-feed speeds many feet of wire can be fed out during a full minute's wire-feed speed test, so a shorter time test is desirable. For example, in Table 11-1 the slowest wire-feed speed for a

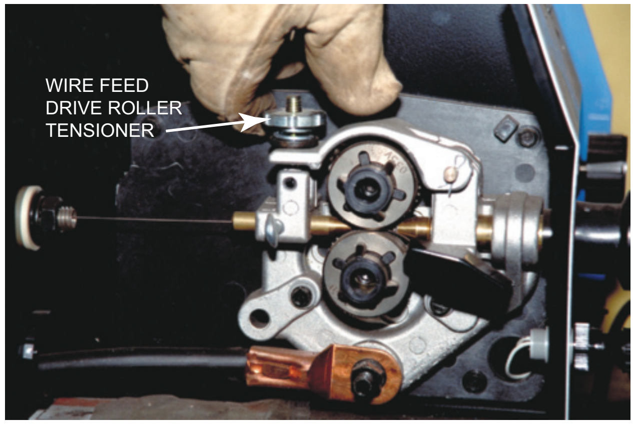

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FIGURE 11-14 Adjust the wire feed tensioner.

0.030 spray arc would be 500 ipm, which is 41 feet of wire per minute; at the highest speed of 650 ipm, 54 feet of wire would be fed per minute. There are two commonly used shorter timed tests to reduce the wasting of electrode. One uses 15 seconds, and the resulting length is multiplied by four to determine the inches per minute. The second test uses six seconds, and the resulting length is multiplied by 10 to determine the inches per minute. The 15-second test is more accurate, but for most applications the six-second test is adequate.

- Snip the end of the wire off at the contact tube.
- Turn on the welding machine.
- Point the welding gun away from metal that might accidentally complete the welding circuit, and squeeze the trigger for six seconds.
- Using a tape measure, check the length of wire.
- Multiply the length of the wire by 10.
- The result is how many inches of wire would be fed in a minute.
- Release the drive roller spring tensioner so that the electrode spool can be hand-turned backward to draw the electrode back onto the spool.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

Recommended GMA Welding Setup for Carbon Steel						
	Short Circuit Arc			Spray Metal Arc		
Electrode Diameter Inch	Amps	Volts	Wire Feed Speed* (IPM)	Amps	Volts	Wire Feed Speed (IPM)
0.023	45-**70**-90	14-**15**-16	150-**300**-380	100-**110**-125	23-**23**-25	400-**450**-620
0.030	60-**100**-140	14-**15**-16	150-**220**-350	160-**180**-200	24-**25**-26	500-**520**-650
0.035	90-**130**-160	15-**17**-19	180-**250**-300	180-**200**-230	25-**26**-27	400-**480**-550
0.045	130-**160**-200	17-**18**-19	125-**150**-200	260-**300**-340	25-**27**-30	300-**350**-500
0.052	150-**160**-200	17-**18**-20	135-**140**-190	275-**325**-400	26-**28**-33	265-**310**-390

BOLD Values represents the optimum setting using DCEP and a shielding gas flow rate from 35 to 45 CFM.
*To check the wire feed speed, run out wire for six seconds, measure its length, and multiply the measurment by ten.

TABLE 11-1 Typical Amperages for Carbon Steel

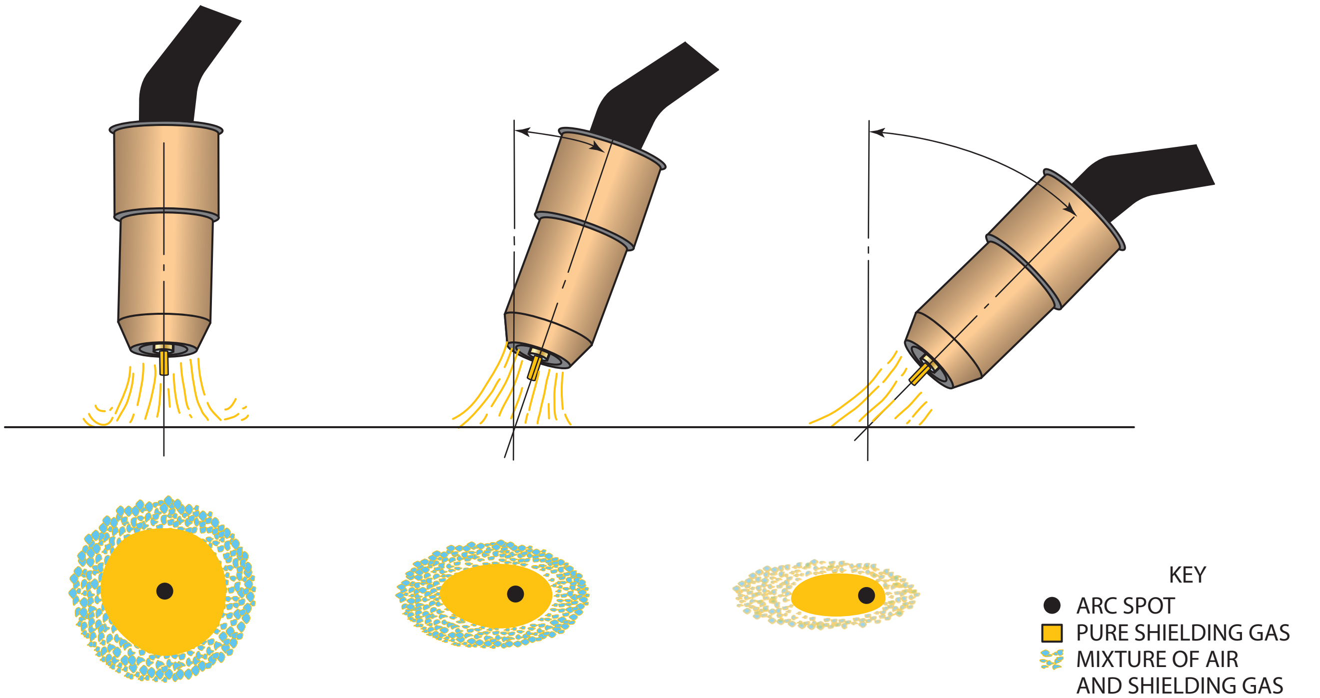

FIGURE 11-15 The welding gun angle affects the shielding gas coverage for the molten weld pool.

THINK GREEN

Save Shielding Gas

Setting the shielding gas flow rate as low as possible within the welding procedure range for your welding conditions will reduce the wasting of this consumable material. Although most shielding gases are renewable, their purchase price is not, so using them sparingly will cut costs.

GAS DENSITY AND FLOW RATES

Density is the chief determinant of how effective a gas is for arc shielding. The lower the density of a gas, the higher will be the **flow rate** required for equal arc protection. Flow rates, however, are not in proportion to the densities. Helium, with approximately one-tenth the density of argon, requires only twice the flow for equal protection.

THINK GREEN

Save Shielding Gas

Setting the shielding gas flow rate as low as possible within the welding procedure range for your welding conditions will reduce the wasting of this consumable material. Although most shielding gases are renewable, their purchase price is not, so using them sparingly will cut costs.

The correct flow rate can be set by checking welding guides that are available from the welding equipment and filler metal manufacturers. These welding guides list the gas flow required for various nozzle sizes and welding amperage settings. Some welders feel that a higher gas flow will provide better weld coverage, but that is not always the case. High gas flow rates waste shielding gases and may lead to contamination. The contamination comes from turbulence in the gas at high flow rates. Air is drawn into the gas envelope by the venturi effect around the edge of the nozzle. Also, the air can be drawn in under the nozzle if the torch is held at too sharp of an angle to the metal, **Figure 11-15**.

Analog gas flow meters have round dials with a needle that points to the flow rate, and digital flow meters have a numeric display that shows the flow rate. The advantage of these types of flow meters is that they are easier to set than the less expensive ball-type flow meters.

NOTE

If you need more shielding gas coverage in a windy or drafty area, use both a larger diameter gas nozzle and a higher gas flow rate. The larger the nozzle size, the higher the permissible flow rate without causing turbulence. Larger nozzle sizes may restrict your visibility of the weld. You might also consider setting up a wind barrier to protect your welding from the wind, **Figure 11-16**.

EXPERIMENT 11-2

Setting Gas Flow Rate

Using the equipment setup as described in Practice 11-1 and the threaded machine as described in Practice 11-2, you will set the shielding gas flow rate.

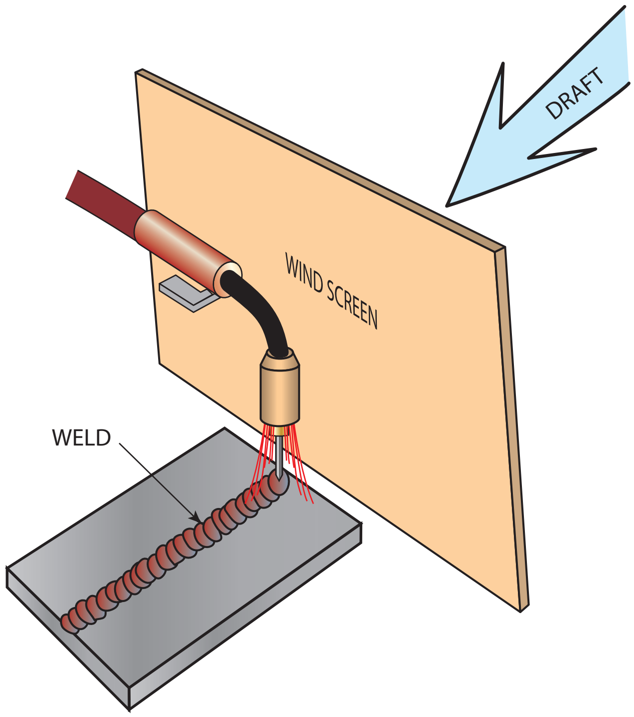

FIGURE 11-16 A windscreen can help prevent the shielding gas from being blown away.

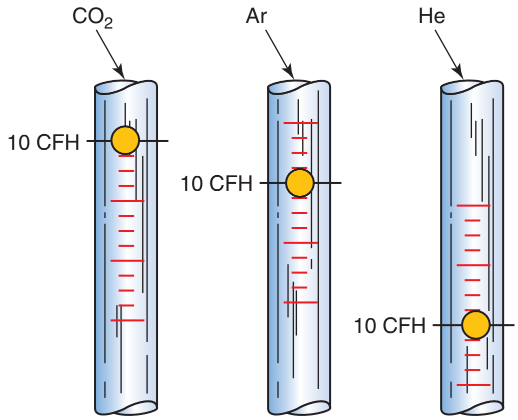

FIGURE 11-17 Each of these gases is flowing at the same cfh (L/min) rate. Because helium (He) is less dense, its indicator ball is the lowest. Be sure that you are reading the correct scale for the gas being used.

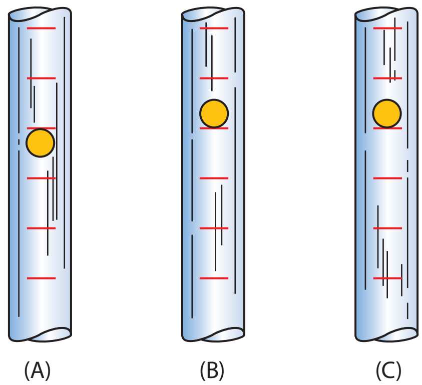

FIGURE 11-18 Three methods of reading a flowmeter: (A) top of ball; (B) center of ball; and (C) bottom of ball.

The exact flow rate required for a certain job will vary depending on welding conditions. This experiment will help you determine how those conditions affect the flow rate. You will start by setting the shielding gas flow rate at 35 cfh (16 L/min).

Turn on the shielding gas supply valve. If the supply is a cylinder, the valve is opened all the way. With the machine power on and the welding gun switch depressed, you are ready to set the flow rate. Slowly turn in the adjusting screw and watch the float ball as it rises in a tube on a column of gas. The faster the gas flows, the higher the ball will float. A scale on the tube allows you to read the flow rate. Different scales are used with each type of gas being used. Because various gases have different densities (weights), the ball will float at varying levels even though the flow rates are the same, **Figure 11-17**. The line corresponding to the flow rate may be read as it compares to the top, center, or bottom of the ball, depending on the manufacturer's instructions. There should be some marking or instruction on the tube or regulator to tell a person how it should be read, **Figure 11-18**.

Release the welding gun switch, and the gas flow should stop. Turn off the power and spray the hose fittings with a leak-detecting solution.

When stopping for a period of time, the shielding gas supply valve should be closed and the hose pressure released.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

ARC-VOLTAGE AND AMPERAGE CHARACTERISTICS

The arc-voltage and amperage characteristics of GMA, FCA, and SA welding are different from most other welding processes. The voltage is set on the welder, and the amperage is set by changing the wire-feed speed. At any one voltage setting the amperage required to melt the wire must change as it is fed into the weld. It requires more amperage to melt the wire the faster it is fed, and less the slower it is fed.

Because changes in the wire-feed speed directly change the amperage, it is possible to set the amperage by using a chart and measuring the length of wire fed per minute, Table 11-1. The voltage and amperage required for specific metal transfer methods differ for various wire sizes, shielding gases, and metals.

The voltage and amperage setting will be specified for all welding done according to a welding procedure specification (WPS) or other codes and standards. However, most welding—like that done in small production shops, such as maintenance welding, for repair work, in farm shops,

and the like—is not done to specific code or standard, and therefore no specific setting exists. For that reason, it is important to learn to make the adjustments necessary to allow you to produce quality welds.

EXPERIMENT 11-3

Setting the Current

Using a properly assembled GMA welding machine, proper safety protection, and one piece of mild steel plate approximately 12 in. (305 mm) long and 1/4 in. (6 mm) thick, you will change the current settings and observe the effect on GMAW.

On a scale of 0 to 10, set the wire-feed speed control dial at 5, or halfway between the low and high settings of the unit. The voltage is also set at a point halfway between the low and high settings. The shielding gas can be CO_2, argon, or a mixture. The gas flow should be adjusted to a rate of 35 cfh (16 L/min).

Hold the welding gun at a comfortable angle, lower your welding hood, and pull the trigger. As the wire feeds and contacts the plate, the weld will begin. Move the gun slowly along the plate. Note the following welding conditions as the weld progresses: voltage, amperage, weld direction, metal transfer, spatter, molten weld pool size, and penetration. Stop and record your observations in **Table 11-2**. Evaluate the quality of the weld as acceptable or unacceptable.

Reduce the voltage somewhat and make another weld, keeping all other weld variables (travel speed, stickout, direction, amperage) the same. Observe the weld and upon stopping record the results. Repeat this procedure until the voltage has been lowered to the minimum value indicated on the machine. Near the lower end, the wire may stick, jump, or simply no longer weld.

Return the voltage indicator to the original starting position and make a short test weld. Stop and compare the results to those first observed. Then, slightly increase the voltage setting and make another weld. Repeat the procedure of observing and recording the results as the voltage is increased in steps until the maximum machine capability is obtained. Near the maximum setting the spatter may become excessive if CO_2 shielding gas is used. Care must be taken to prevent the wire from fusing to the contact tube.

Return the voltage indicator to the original starting position and make a short test weld. Compare the results observed with those previously obtained.

Lower the wire-feed speed setting slightly and use the same procedure as before. First lower and then raise the voltage through a complete range and record your observations. After a complete set of test results is obtained from this amperage setting, again lower the wire-feed speed for a new series of tests. Repeat this procedure until the amperage is at the minimum setting shown on the machine. At low amperages and high voltage settings, the wire may tend to pop violently as a result of the uncontrolled arc.

Return the wire-feed speed and voltages to the original settings. Make a test weld and compare the results with the original tests. Slightly raise the wire speed and again run a set of tests as the voltage is changed in small steps. After each series, return the voltage setting to the starting point and increase the wire-feed speed. Make a new set of tests.

All of the test data can be gathered into an operational graph for the machine, wire type, size, and shielding gas. Use **Table 11-3** to plot the graph. The acceptable welds should be marked on the lines that extend from the appropriate voltages and amperages. Upon completion, the graph will give you the optimum settings for the operation of this particular GMAW setup. The optimum settings are along a line in the center of the acceptable welds.

Experienced welders will follow a much shorter version of this type of procedure any time they are starting to work on a new machine or testing for a new job. This experiment can be repeated using different types of wire, wire sizes, shielding gases, and weld directions. Turn off the welding machine and shielding gas and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

Weld Acceptability	Voltage	Amperage	Spatter	Molten Pool Size	Penetration
Good	20	75	Light	Small	Little

Electrode diameter	.035 in. (0.9 mm)
Shielding gas	CO_2
Welding direction	Backhand

TABLE 11-2 Setting the Current

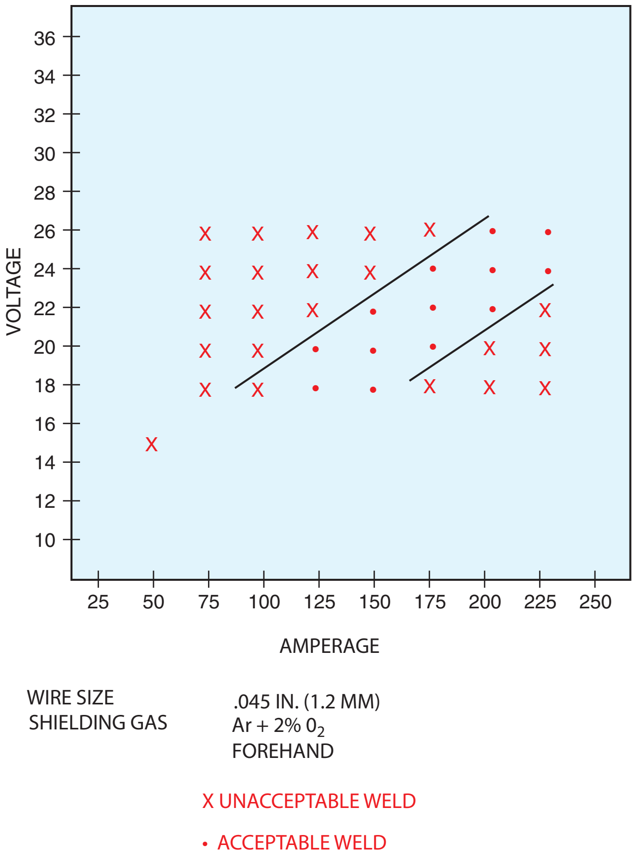

TABLE 11-3 Graph for GMAW Machine Settings

ELECTRODE EXTENSION

Because of the constant-potential (CP) power supply, the welding current will change as the distance between the contact tube and the work changes. Although this change is slight, it is enough to affect the weld being produced. The longer the electrode extension, the greater the resistance to the welding current flowing through the small welding wire. This results in some of the welding current being changed to heat at the tip of the electrode, **Figure 11-19**.

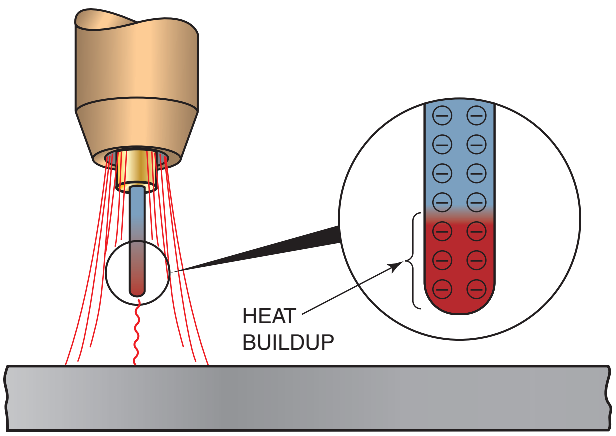

FIGURE 11-19 Heat buildup due to the extremely high current for the small conductor (electrode).

With a standard SMA welding CC power supply this would also reduce the arc voltage, but with a CP power supply the voltage remains constant and the amperage increases. If the electrode extension is shortened, the welding current decreases.

The increase in current does not result in an increase in penetration because the current is being used to heat the electrode tip and is not being transferred to the weld metal. Penetration is reduced and buildup is increased as the electrode extension is lengthened. Penetration is increased and buildup is decreased as the electrode extension is shortened. Controlling the weld penetration and buildup by changing the electrode will help maintain weld bead shape during welding. It will also help you better understand what may be happening if a weld starts out correctly but begins to change as it progresses along the joint. You may be changing the electrode extension without noticing the change. Short electrode stickout gives a hotter weld and long stickout results in a cooler weld.

EXPERIMENT 11-4

Electrode Extension

Using a properly assembled GMA welding machine, proper safety protection, and a few pieces of mild steel, each approximately 12 in. (305 mm) long and ranging in thickness from 16 gauge to 1/2 in. (13 mm), you will observe the effect of changing electrode extension on the weld.

Start at a low current setting. Using the graph developed in Experiment 11-2, set both the voltage and amperage. The settings should be equal to those on the optimum line established for the wire type and size being used with the same shielding gas.

Holding the welding gun at a comfortable angle and height, lower your helmet and start to weld. Make a weld approximately 2 in. (51 mm) long. Then, reduce the distance from the gun to the work while continuing to weld. After a few inches, again shorten the electrode extension even more. Keep doing this in steps until the nozzle is as close as possible to the work. Stop and return the gun to the original starting distance.

Repeat the process just described but now increase the electrode extension, making welds of a few inches each. Keep increasing the electrode extension until the weld will no longer fuse or the wire becomes impossible to control.

Change the plate thickness and repeat the procedure. When the series has been completed with each plate thickness, raise the voltage and amperage to a medium setting and repeat the process. Upon completing this series of tests, adjust the voltage and amperage upward to a high setting. Make a full series of tests using the same procedures as before.

Record the results in **Table 11-4** after each series of tests. The final results can be plotted on a graph, as was done in **Table 11-5**, to establish the optimum electrode extension for each thickness, voltage, and amperage. Turn

Weld Acceptability	Voltage	Amperage	Electrode Extension	Contact Tube-to-Work Distance	Bead Shape
Poor	20	100	1 in. (25 mm)	1 1/4 in. (31 mm)	Narrow, high, with little penetration

Electrode diameter	.035 in. (0.9 mm)
Shielding gas	CO_2
Welding direction	Forehand

TABLE 11-4 Electrode Extension

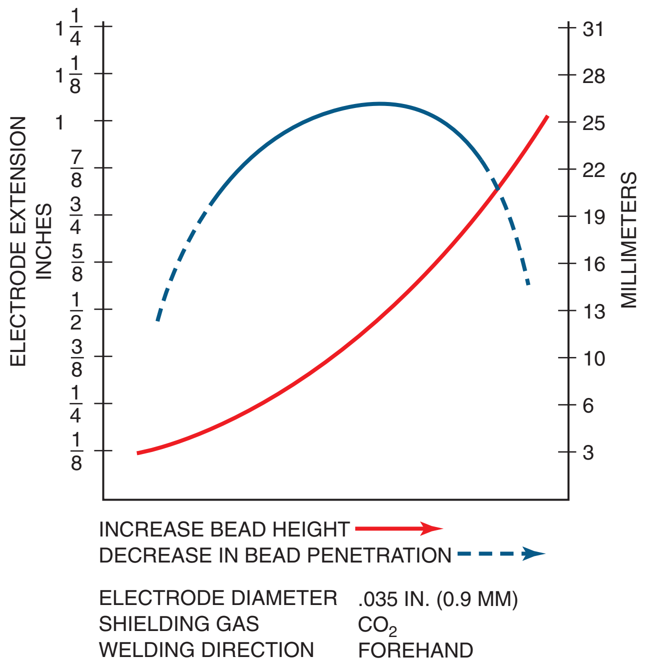

TABLE 11-5 Plot of Experiment 11-4 Results

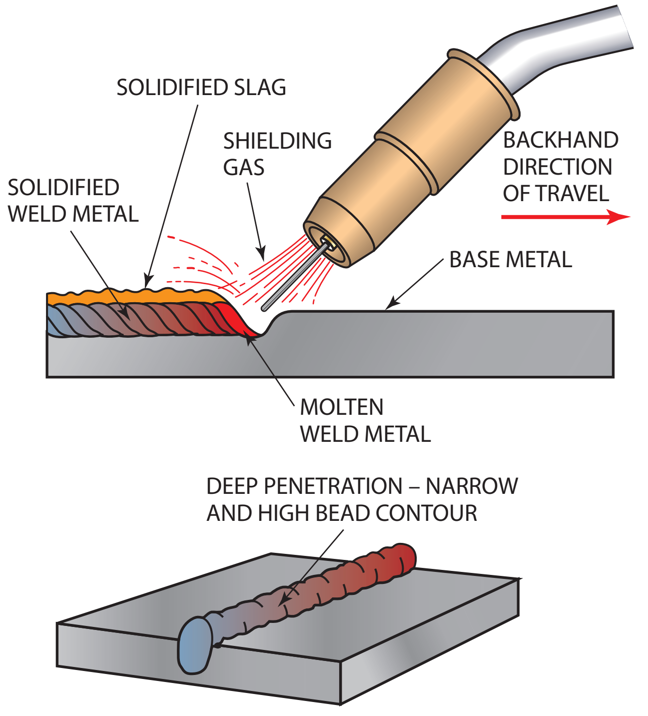

FIGURE 11-20 Backhand welding or dragging angle.

off the welding machine and shielding gas and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

WELDING GUN ANGLE

The term *welding gun angle* refers to the angle between the GMA welding gun and the work as it relates to the direction of travel. Backhand welding, or dragging angle, **Figure 11-20**, produces a weld with deep penetration and higher buildup. Forehand welding, or pushing angle, **Figure 11-21**, produces a weld with shallow penetration and little buildup. Perpendicular welding has a good balance between penetration and reinforcement, **Figure 11-22**.

Slight changes in the welding gun angle can be used to control the weld as the groove spacing changes. A narrow gap may require more penetration, but as the gap spacing increases, a weld with less penetration may be required. Changing the electrode extension and welding gun angle at the same time can result in a quality weld being made under conditions that are less than ideal.

EXPERIMENT 11-5

Welding Gun Angle

Using a properly assembled GMA welding machine, proper safety protection, and some pieces of mild steel, each approximately 12 in. (305 mm) long and ranging in thickness from 16 gauge to 1/2 in. (13 mm), you will observe the effect of changing the welding gun angle on the weld bead.

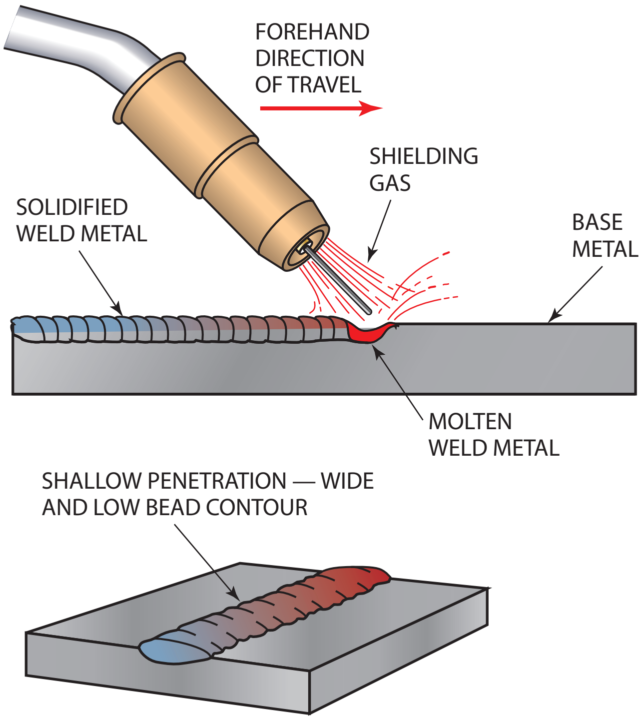

FIGURE 11-21 Forehand welding or pushing angle.

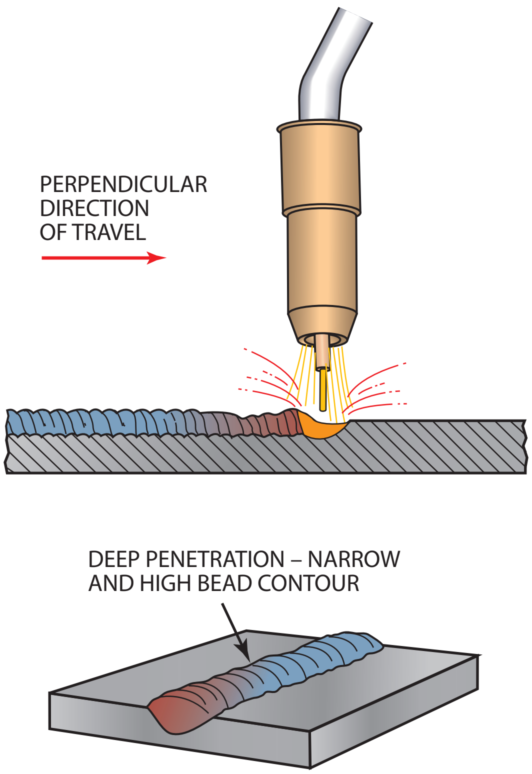

FIGURE 11-22 Perpendicular gun angle.

Starting with a medium current setting and a plate that is 1/4 in. (6 mm) thick, hold the welding gun at a 30° angle to the plate in the direction of the weld, **Figure 11-23**. Lower your welding hood and depress the trigger. When

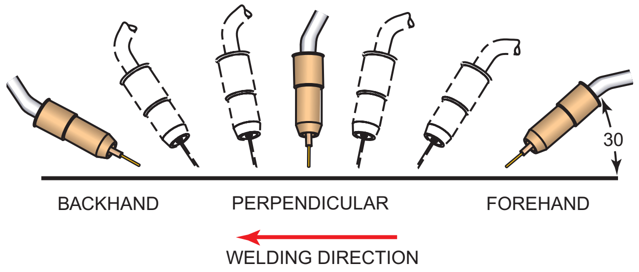

FIGURE 11-23 Welding gun angle.

the weld starts, move in a straight line and slowly pivot the gun angle as the weld progresses. Keep the travel speed, electrode extension, and weave pattern (if used) constant so that any change in the weld bead is caused by the angle change.

The pivot should be completed in the 12 in. (305 mm) of the weld. You will proceed from a 30° pushing angle to a 30° dragging angle. Repeat this procedure using different welding currents and plate thicknesses.

After the welds are complete, note the differences in width and reinforcement along the welds. Turn off the welding machine and shielding gas and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

EFFECT OF SHIELDING GAS ON WELDING

Shielding gases in the gas metal arc process are used primarily to protect the molten metal from oxidation and contamination. Other factors must be considered, however, in selecting the right gas for a particular application. Shielding gas can influence arc and metal transfer characteristics, weld penetration, width of fusion zone, surface shape patterns, welding speed, and undercut tendency. Inert gases such as argon and helium provide the necessary shielding because they do not form compounds with any other substance and are insoluble in molten metal. When used as pure gases for welding ferrous metals, argon and helium may produce an erratic arc action, promote undercutting, and result in other flaws.

It is therefore usually necessary to add controlled quantities of reactive gases to achieve good arc action and metal transfer with these materials. Adding oxygen or carbon dioxide to the inert gas tends to stabilize the arc, promote favorable metal transfer, and minimize spatter. As a result, the penetration pattern is improved and undercutting is reduced or eliminated.

Oxygen or carbon dioxide is often added to argon. The amount of reactive gas required to produce the desired effects is quite small. As little as 0.5% of oxygen will produce a noticeable change; 1% to 5% of oxygen is more common. Carbon dioxide may be added to argon in the

20% to 30% range. Mixtures of argon with less than 10% carbon dioxide may not have enough arc voltage to give the desired results.

Adding oxygen or carbon dioxide to an inert gas causes the shielding gas to become oxidizing. This, in turn, may cause porosity in some ferrous metals. In this case, a filler wire containing suitable deoxidizers should be used. The presence of oxygen in the shielding gas can also cause some loss of certain alloying elements, such as chromium, vanadium, aluminum, titanium, manganese, and silicon. Again, the addition of a deoxidizer to the filler wire is necessary.

Pure carbon dioxide has become widely used as a shielding gas for GMA welding of steels. It allows higher welding speed, better penetration, and good mechanical properties, and it costs less than the inert gases. The chief drawbacks in the use of carbon dioxide are the less-steady arc characteristics and considerable weld-metal spatter losses. The spatter can be kept to a minimum by maintaining a very short, uniform arc length. Consistently sound welds can be produced using carbon dioxide shielding, provided that a filler wire with the proper deoxidizing additives is used.

EXPERIMENT 11-6

Effect of Shielding Gas Changes

Using a properly assembled GMA welding machine, proper safety protection, a source of CO_2, argon, and oxygen gases or a variety of premixed shielding gases, two flowmeters (or one two-gas mixing regulator), and some pieces of mild steel plate, each approximately 12 in. (305 mm) long and ranging in thickness from 16 gauge to 1/2 in. (13 mm), you will observe the effect of various shielding gas mixtures on the weld.

Using a mixing flowmeter regulator will allow the gases to be mixed in any desired combination. A mixing ratio chart for use in arriving at the approximate gas percentages appears in **Table 11-6**. The exact ratios are not so important to you, as a student, as they are on code work.

With a medium voltage and amperage setting and using a 100% carbon dioxide (CO_2) shielding gas, start making a weld. Either change the mixture after each weld or have another person change the shielding gas during the weld. Keep the total flow rate the same by adding argon (Ar) while reducing the CO_2 to preserve the same flow rate. During the experiment, change over the shielding gas to 100% argon (Ar).

After the weld is complete, evaluate it for spatter, penetration, undercut, buildup, width, or other noticeable changes along its length. Using **Table 11-7**, record the results of your evaluation.

Repeat the procedure just explained two more times with both low and high power settings. Again, record your observations.

Starting with 100% argon (Ar), add oxygen (O_2) to the shielding gas. The oxygen percentage will range from 0% to 10%, **Table 11-8**. Very slight changes in the percentage will have dramatic effects on the weld. You will make three welds using low, medium, and high power settings. For each weld, you will record your observations.

During some of the welding tests, you will notice a change in the method of metal transfer, weld heat, and

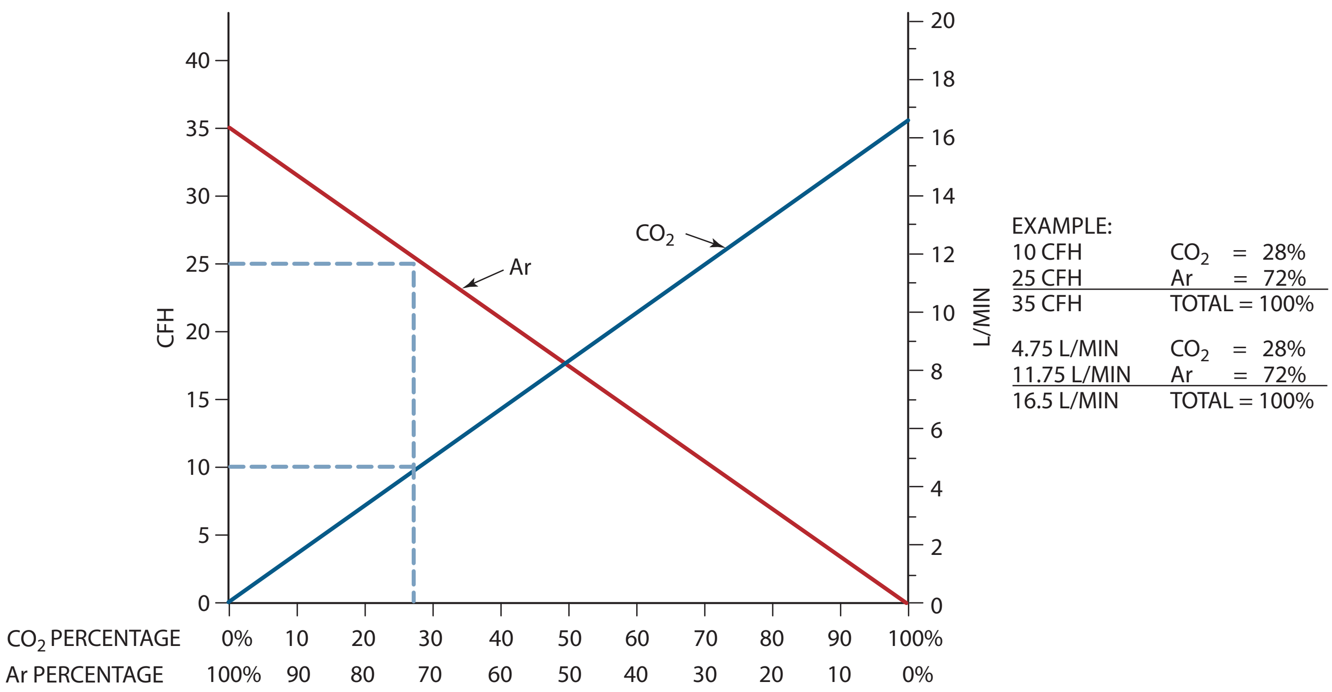

TABLE 11-6 Gas Mixing Percentages

Weld Acceptability	Voltage	Spatter	Penetration	Puddle Size	Bead Appearance
Good	75 Ar 25 CO^2	Very Little	Deep	Large	Wide with little buildup

Electrode diameter	.035 in. (0.9 mm)
Welding direction	Forehand
Voltage	25
Amperage	150

TABLE 11-7 Shielding Gas Mixtures

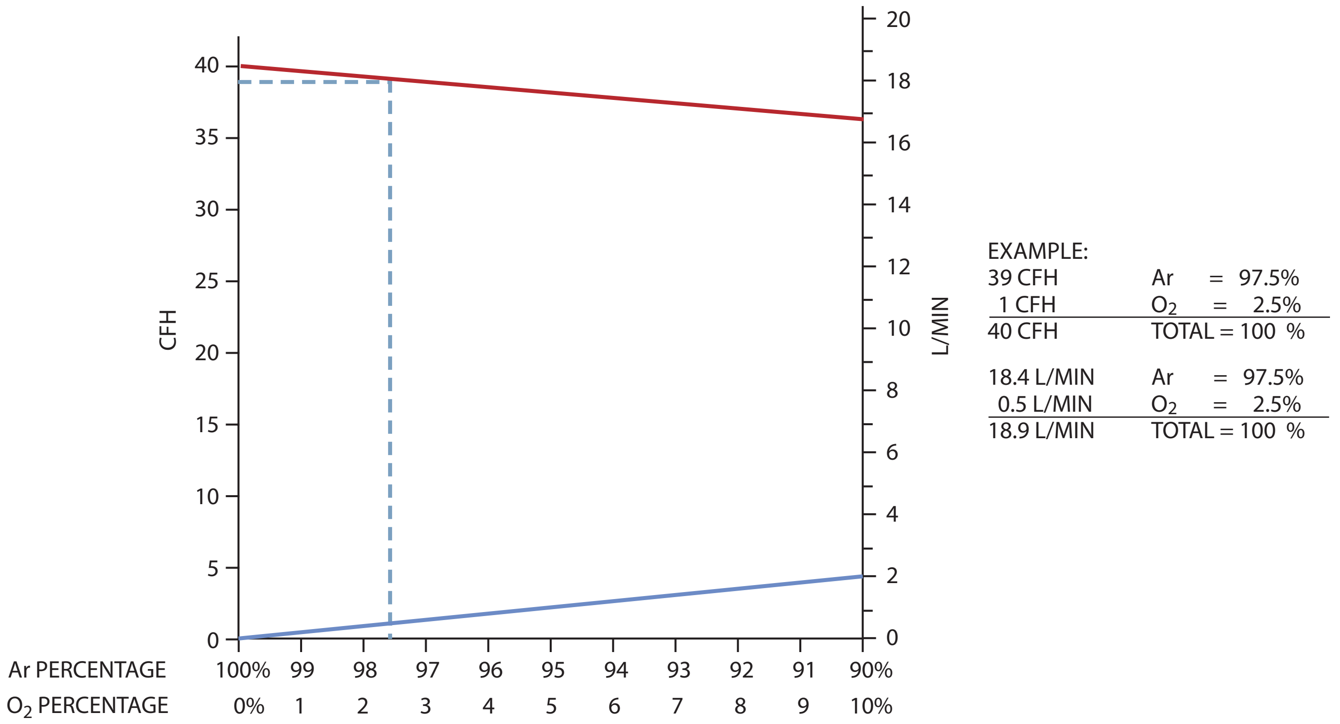

TABLE 11-8 Ar and O_2 Mixture Percentages

general weld performance without a change in the current settings. The shielding gas mixture can have major effects on the rate of metal transfer and the welding speed, as well as other welding variables. Higher speeds and greater production can be obtained by using some gas mixtures. However, the savings can be completely offset by the higher gas cost. Before making a final decision about the gas to be used, all the variables must be compared. **Table 11-9** lists premixed shielding gases and their uses. Turn off the welding machine and shielding gas and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICES

The practices in this chapter are grouped according to those requiring similar techniques and setups. To make acceptable GMA welds consistently, the major skill required is the ability to set up the equipment and weldment. Changes such as variations in material thickness, position, and type of joint require changes both in technique and setup. A correctly set up GMA welding station can, in many cases, be operated with minimum skill. Often, the only difference between a welder earning a minimum wage and one earning the maximum wage is the ability to make correct machine setups.

Shielding Gas	Chemical Behavior	Uses and Usage Notes
1. Argon	Inert	Welding virtually all metals except steel
2. Helium	Inert	Al and Cu alloys for greater heat and to minimize porosity
3. Ar and He (20% to 80% to 50% to 50%)	Inert	Al and Cu alloys for greater heat and to minimize porosity but with quieter, more readily controlled arc action
4. N_2	Reducing	On Cu, very powerful arc
5. Ar + 25% to 30% N_2	Reducing	On Cu, powerful but smoother operating, more readily controlled arc than with N_2
6. Ar + 1% to 2% O_2	Oxidizing	Stainless and alloy steels, also for some deoxidized copper alloys
7. Ar + 3% to 5% O_2	Oxidizing	Plain carbon, alloy, and stainless steels (generally requires highly deoxidized wire)
8. Ar + 3% to 5% O_2	Oxidizing	Various steels using deoxidized wire
9. Ar + 20% to 30% O_2	Oxidizing	Various steels, chiefly with short-circuiting arc
10. Ar + 5% O_2 + 15% CO_2	Oxidizing	Various steels using deoxidized wire
11. CO_2	Oxidizing	Plain carbon and low alloy steels, deoxidized wire essential
12. CO_2 + 3% to 10% O_2	Oxidizing	Various steels using deoxidized wire
13. CO_2 + 20% O_2	Oxidizing	Steels

TABLE 11-9 Shielding Gases and Gas Mixtures Used for Gas Metal Arc Welding

Ideally, only a few tests would be needed for the welder to make the necessary adjustments in setup and manipulation techniques to achieve a good weld. The previous welding experiments should have given the welder a graphic set of comparisons to help that welder make the correct changes. In addition to keeping the test data, you may want to keep the test plates for a more accurate comparison.

The grouping of practices in this chapter will keep the number of variables in the setup to a minimum. Often, the only change required before going on to the next weld is to adjust the power settings.

Figures that are given in some of the practices will give the welder general operating conditions, such as voltage, amperage, and shielding gas and/or gas mixture. These are general values, so the welder will have to make some fine adjustments. Differences in the type of machine being used and the material surface condition will affect the settings. For this reason, it is preferable to use the settings developed during the experiments.

METAL PREPARATION

All hot-rolled steel has an oxide layer, which is formed during the rolling process, called mill scale. *Mill scale* is a thin layer of dark gray or black iron oxide. Some hot-rolled steels that have had this layer removed either mechanically or chemically can be purchased. However, almost all of the hot-rolled steel used today still has this layer because it offers some protection from rusting.

Mill scale is not removed for noncode welding because it does not prevent most welds from being suitable for service. For practice welds that will be visually inspected, mill scale can usually be left on the plate. Filler metals and fluxes usually have deoxidizers added to them so that the adverse effects of the mill scale are reduced or eliminated, **Table 11-10**. But with GMA welding wire, it is difficult to add enough deoxidizers to remove all effects of mill scale. The porosity that mill scale causes is most often confined

Deoxidizing Element	Strength
Aluminum (Al)	Very strong
Manganese (Mn)	Weak
Silicon (Si)	Weak
Titanium (Ti)	Very strong
Zirconium (Zr)	Very strong

TABLE 11-10 Sufficient Deoxidizing Elements Must Be Added to the Filler Wire to Minimize Porosity in the Molten Weld Pool

to the interior of the weld and is not visible on the surface, **Figure 11-24**. Because it is not visible on the surface, it usually goes unnoticed and the weld passes visual inspection.

If the practices are going to be destructively tested or if the work is of a critical nature, then all welding surfaces

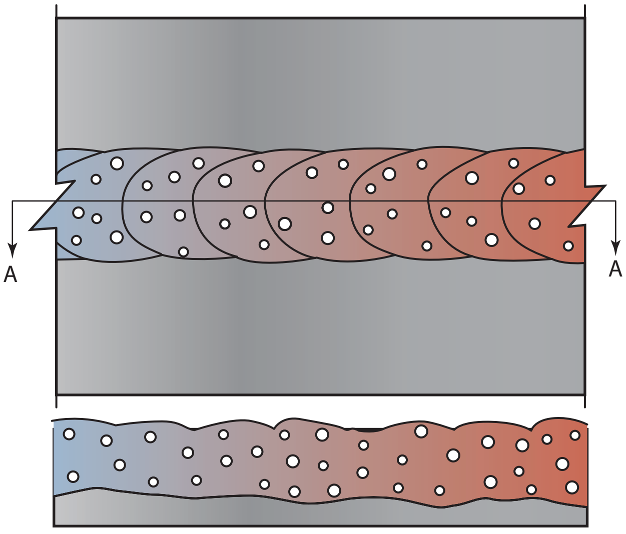

FIGURE 11-24 Uniformly scattered porosities.

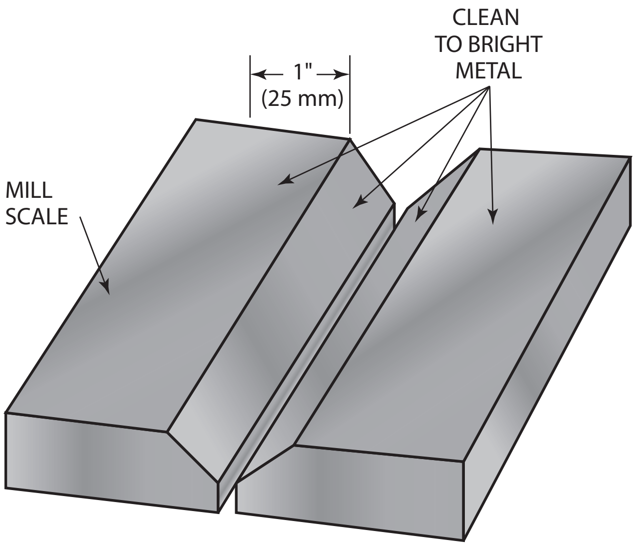

FIGURE 11-25 Clean all surfaces to bright metal before welding.

within the weld groove and the surrounding surfaces within 1 in. (25 mm) must be cleaned to bright metal, **Figure 11-25**. Cleaning may be grinding, filing, sanding, or sand blasting.

FLAT POSITION, 1G AND 1F POSITIONS

PRACTICE 11-3

Stringer Beads Using the Short-Circuiting Metal Transfer Method in the Flat Position

Using a properly set up and adjusted GMA welding machine, **Table 11-11**, proper safety protection, 0.035-in. and/or 0.045-in. (0.9-mm and/or 1.2-mm) diameter wire, and two or more pieces of mild steel sheet 12 in. (305 mm) long, 16 gauge, and 1/8 in. (3 mm) thick, you will make a stringer bead weld in the flat position, **Figure 11-26**.

Starting at one end of the plate and using either a pushing or dragging technique, make a weld bead along the entire 12-in. (305-mm) length of the metal. After the weld is complete, check its appearance. Make any needed changes to correct the weld (refer to Table 11-3 and Table 11-5). Repeat the weld and make additional adjustments. After the machine is set, start to work on improving the straightness and uniformity of the weld.

Keeping the bead straight and uniform can be difficult because of the limited visibility due to the small amount of light and the size of the molten weld pool. The welder's view is further restricted by the shielding gas nozzle, **Figure 11-27**. Even with limited visibility, it is possible to make a satisfactory weld by watching the edge of the molten weld pool, the sparks, and the weld bead produced. Watching the leading edge of the molten weld pool (forehand welding, pushing technique) will show you the molten weld pool fusion and width. Watching the trailing edge of the molten weld pool (backhand welding, dragging technique) will show you the amount of buildup and the relative heat input, **Figure 11-28**. The quantity and size of sparks produced can indicate the relative location of the filler wire in the molten weld pool. The number of sparks will increase as the wire strikes the solid metal ahead of the molten weld pool. The gun itself will begin to vibrate or bump as the wire momentarily pushes against the cooler, unmelted base metal before it melts. Changes in weld width, buildup, and proper joint tracking can be seen by watching the bead as it appears from behind the shielding gas nozzle.

Repeat each type of bead as needed until consistently good beads are obtained. Turn off the welding machine and shielding gas and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 11-4

Flat Position Butt Joint, Lap Joint, and Tee Joint

Using the same equipment, materials, and procedures as listed in Practice 11-3, make welded butt joints, lap joints, and tee joints in the flat position, **Figure 11-29A**, **B**, and **C**.

- Tack weld the sheets together and place them flat on the welding table, **Figure 11-30**.
- Starting at one end, run a bead along the joint. Watch the molten weld pool and bead for signs that a change in technique may be required.
- Make any needed changes as the weld progresses. By the time the weld is complete, you should be making the weld nearly perfectly.

Process	Wire Diameter	Amperage Range (Optimum)	Voltage Range (Optimum)	Shielding Gas
Short circuiting	0.030	60 (100) 140	14 (15) 16	100% CO_2 75% Ar + 25% CO_2 98% Ar + 2% O
	0.035	90 (130) 150	16 (17) 20	

TABLE 11-11 Typical Welding Current Settings for Short-Circuiting Metal Transfer for Mild Steel

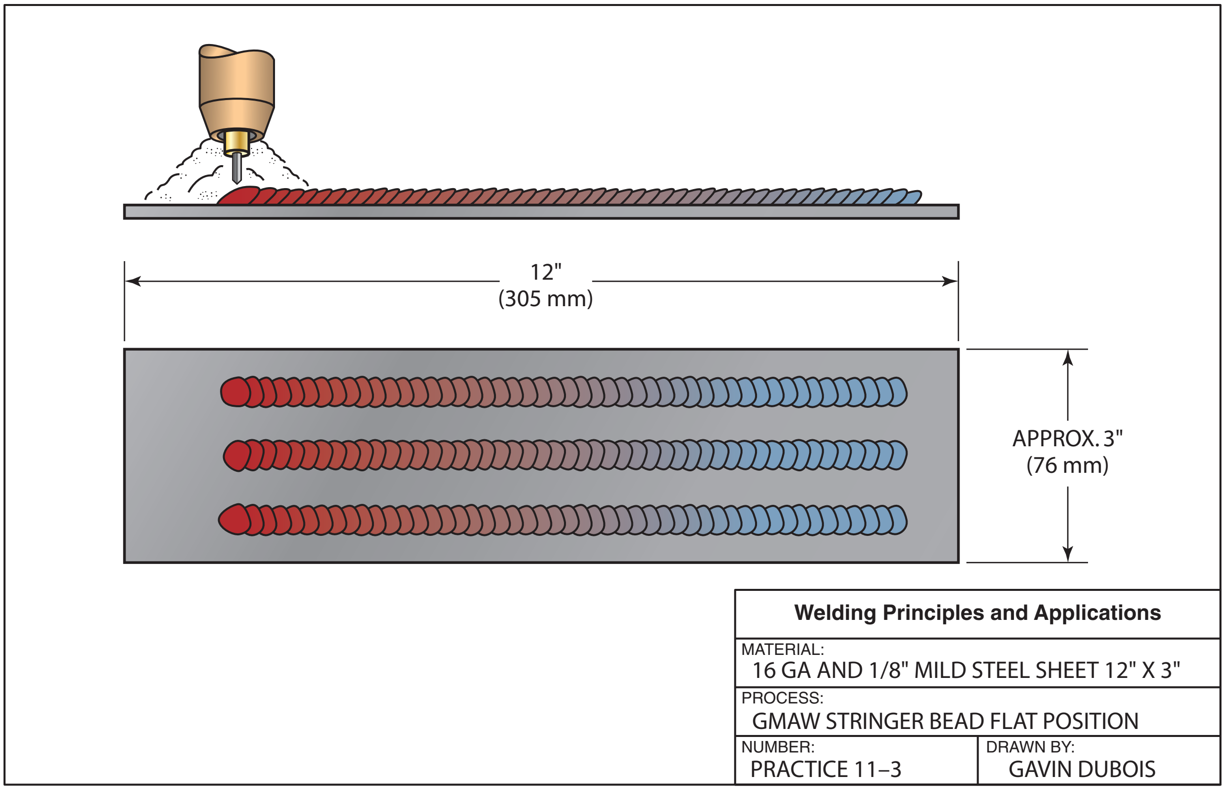

FIGURE 11-26 Stringer beads in the flat position.

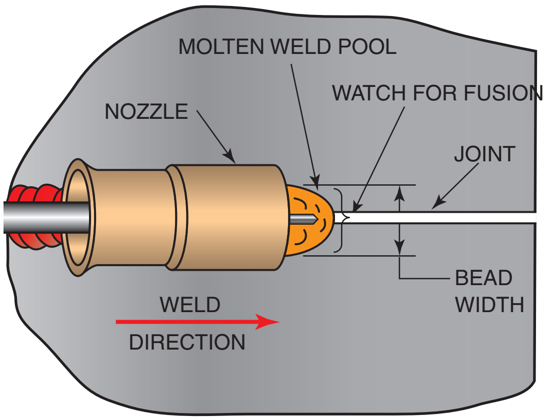

FIGURE 11-27 The shielding gas nozzle restricts the welder's view.

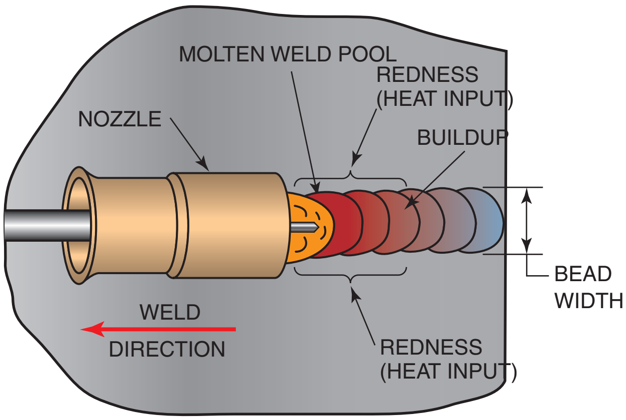

FIGURE 11-28 Watch the trailing edge of the molten weld pool.

- Using the same technique that was established in the last weld, make another weld. This time, the entire 12 in. (305 mm) of weld should be flawless.

Repeat each type of joint with both thicknesses of metal as needed until consistently good beads are obtained. Turn off the welding machine and shielding gas and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 11-5

Flat Position Butt Joint with 100% Penetration

Using the same equipment, materials, and setup as listed in Practice 11-3, make a welded joint in the flat position with 100% penetration along the entire 12-in. (305-mm) length of the welded joint. Repeat the butt weld needed until consistently good beads are obtained. Turn off the

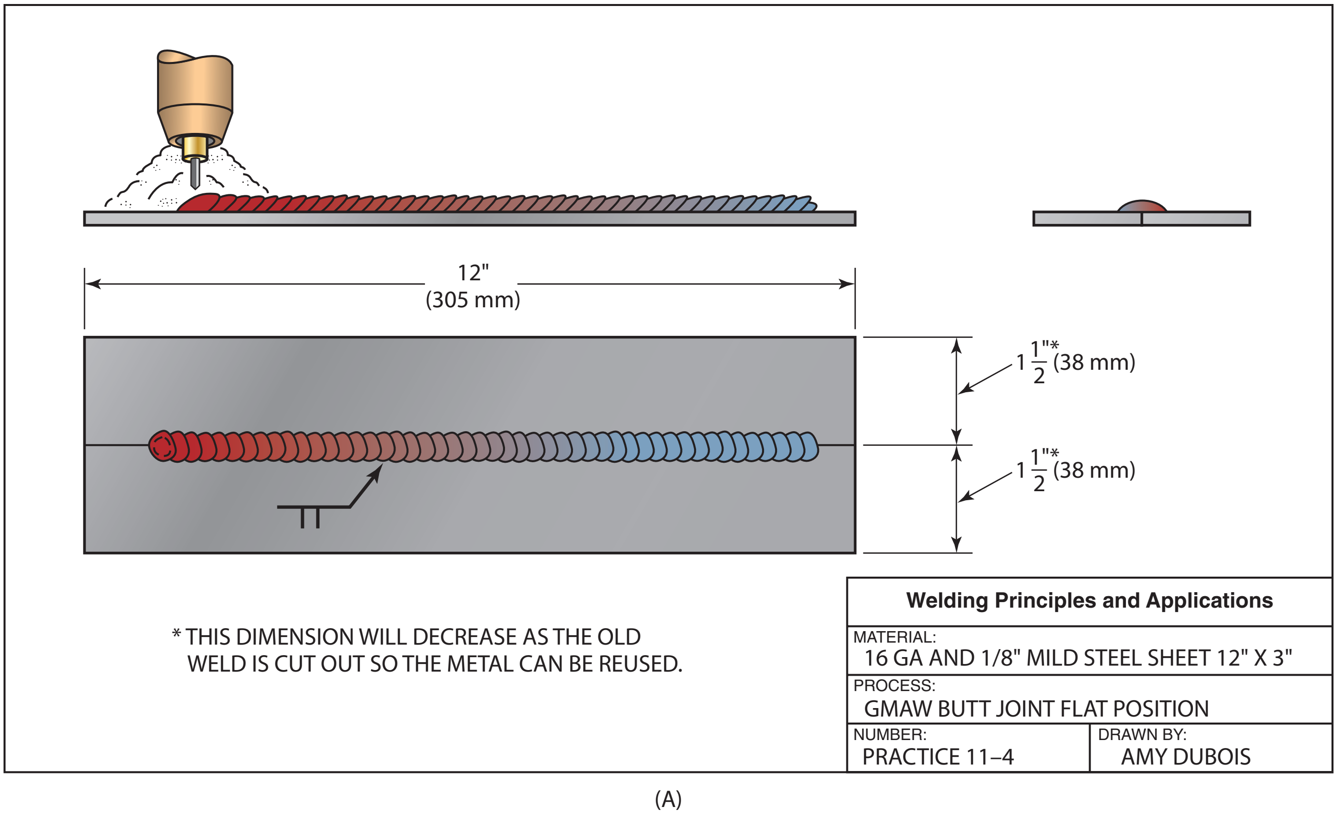

FIGURE 11-29 (A) Butt joint in the flat position.

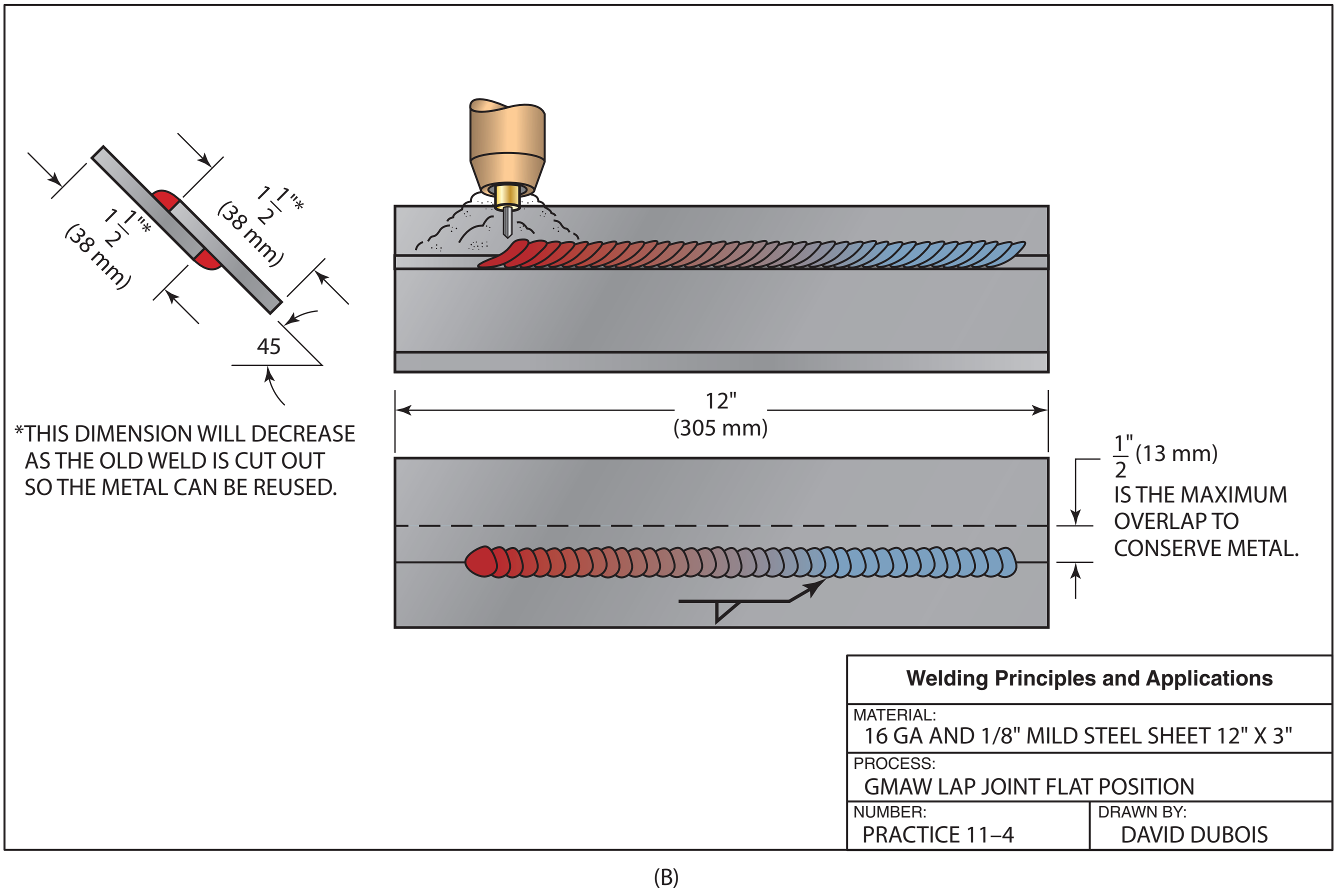

FIGURE 11-29 (B) Lap joint in the flat position.

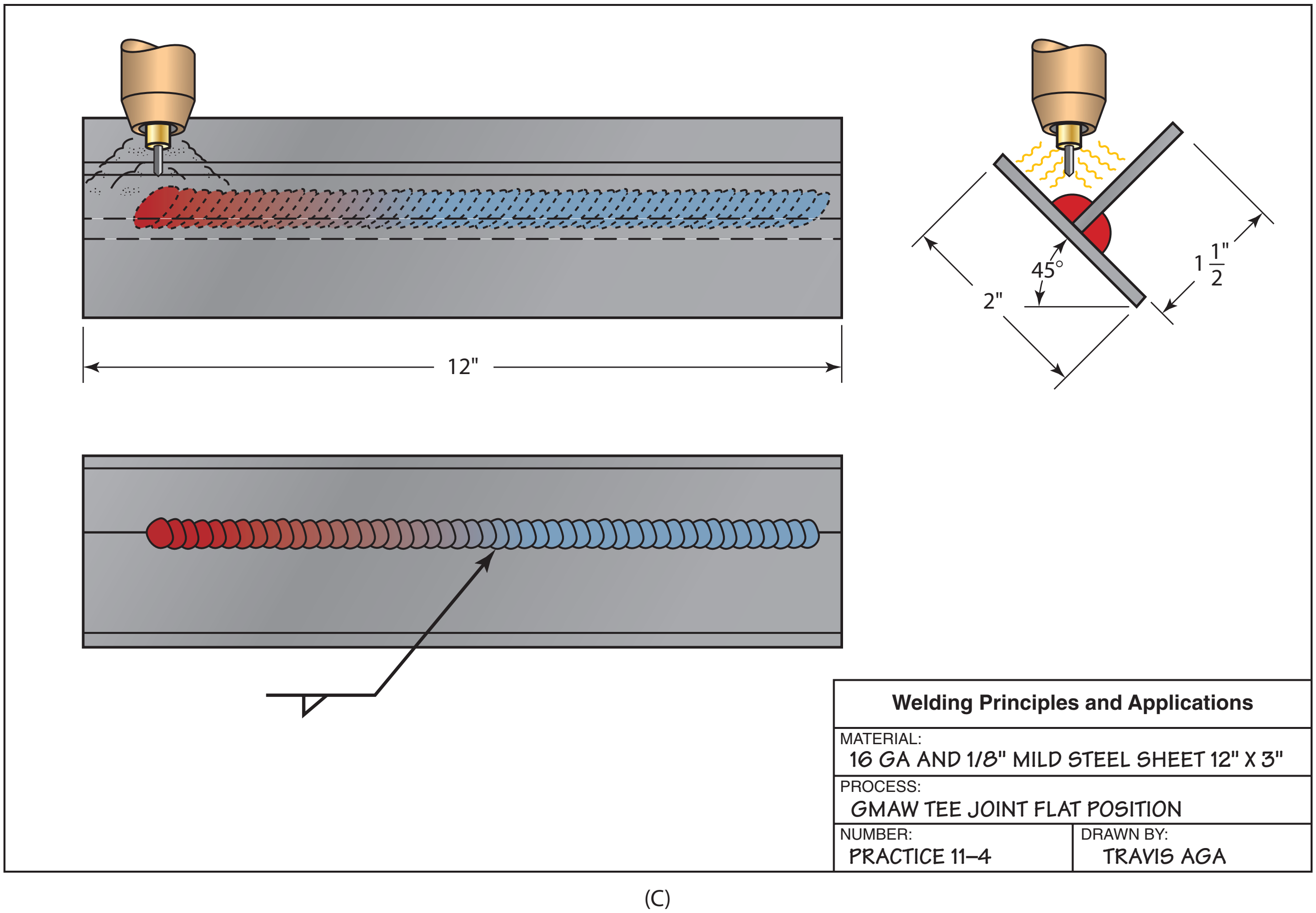

FIGURE 11-29 (C) Tee joint in the flat position.

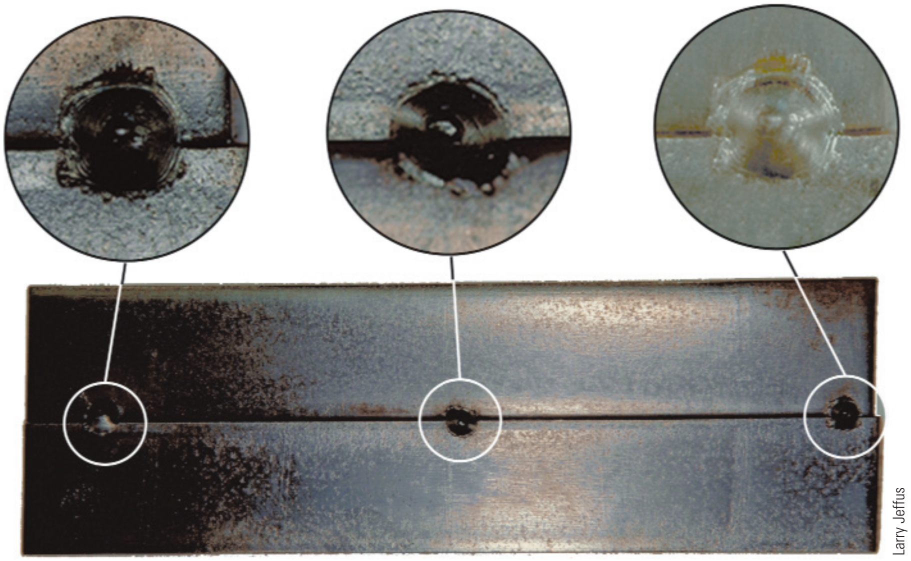

FIGURE 11-30 Use enough tack welds to keep the joint in alignment during welding. Small tack welds are easier to weld over without adversely affecting the weld.

welding machine and shielding gas and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

VERTICAL UP 3G AND 3F POSITIONS

PRACTICE 11-6

Stringer Bead at a 45° Vertical Up Angle

Using the same equipment, materials, and setup as listed in Practice 11-3, you will make a vertical up stringer bead on a plate at a 45° inclined angle.

Start at the bottom of the plate and hold the welding gun at a slight pushing or upward angle to the plate, **Figure 11-31**. Brace yourself, lower your hood, and begin to weld. Depending on the machine settings and type of shielding gas used, you will make a weave pattern.

If the molten weld pool is large and fluid (hot), raise the welding gun slightly to increase the electrode extinction and/or use a "C" or "J" weave pattern to allow a longer time for the molten weld pool to cool, **Figure 11-32**. Do not make the weave so long or fast that the wire is allowed to strike the metal ahead of the molten weld pool. If this happens, spatter increases and a spot or zone of incomplete fusion may occur, **Figure 11-33**.

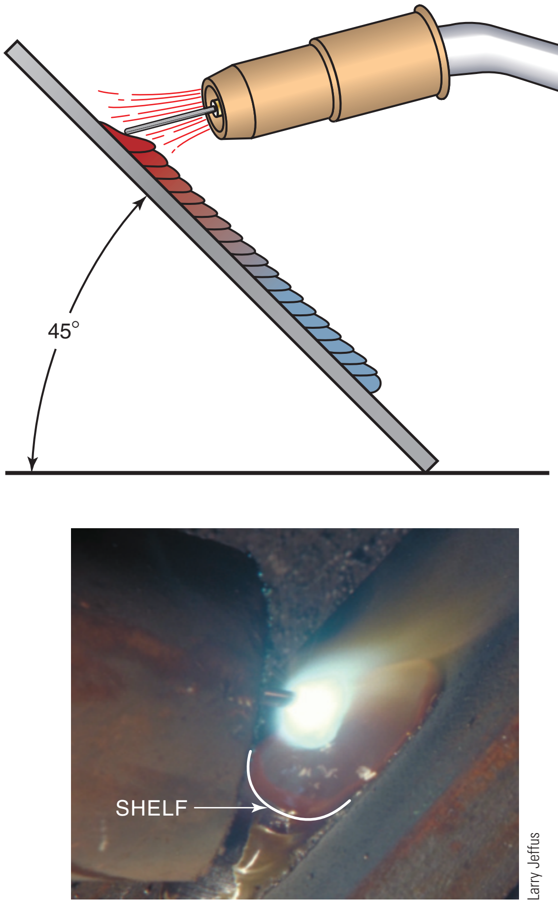

FIGURE 11-31 Vertical up position.

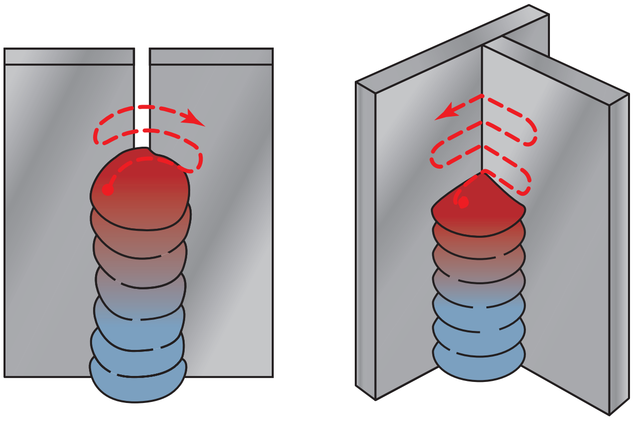

FIGURE 11-32 Vertical up welding weave patterns.

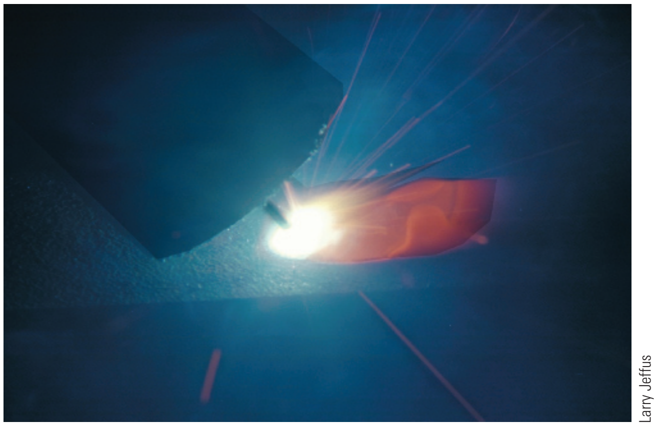

FIGURE 11-33 Burst of spatter caused by incorrect electrode contact with base metal.

If the molten weld pool is small and controllable, use a small "C," zigzag, or "J" weave pattern to control the width and buildup of the weld. A slower speed can also be used. Watch for complete fusion along the leading edge of the molten weld pool. **Figure 11-34** shows a weld that did not fuse with the plate.

FIGURE 11-34 Weld separated from the plate; there is no fusion between the weld and plate.

A weld that is high and has little or no fusion is too "cold." Changing the welding technique will not correct this problem. The welder must stop welding and make the needed adjustments.

As the weld progresses up the plate, the back or trailing edge of the molten weld pool will cool, forming a shelf to support the molten metal. Watch the shelf to be sure that molten metal does not run over, forming a drip. When it appears that the metal may flow over the shelf, increase the weave lengths, lengthen the electrode extension, or stop and start the current for brief moments to allow the weld to cool. Stopping for brief moments will not allow the shielding gas to be lost.

Continue to weld along the entire 12-in. (305-mm) length of plate. Repeat this weld as needed until a straight and uniform weld bead is produced. Turn off the welding machine and shielding gas and clean up your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 11-7

Stringer Bead in the Vertical Up Position

Repeat Practice 11-6 and increase the angle of the plate until you have mastered a straight and uniform weld bead in the vertical up position. Turn off the welding machine and shielding gas and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 11-8

Butt Joint, Lap Joint, and Tee Joint in the Vertical Up Position at a 45° Angle

Using the same equipment, materials, and setup as listed in Practice 11-3, you will make vertical up welded joints on a plate at a 45° inclined angle.

Tack weld the metal pieces together and brace them in position. Check to see that you have free movement along the entire joint to prevent stopping and restarting during the weld. Avoiding stops and starts both speeds up the welding time and eliminates discontinuities.

The weave pattern should allow for adequate fusion on both edges of the joint. Watch the edges to be sure that they are being melted so that adequate fusion and penetration occur.

Repeat each type of joint as needed until consistently good beads are obtained. Turn off the welding machine and shielding gas and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 11-9

Butt Joint in the Vertical Up Position with 100% Penetration

Using the same equipment, materials, and setup as listed in Practice 11-3, you will increase the plate angle gradually as you develop skills until you are making satisfactory welds in the vertical up position.

Repeat the butt joint weld as needed until consistently good beads are obtained. Turn off the welding machine and shielding gas and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

VERTICAL DOWN 3G AND 3F POSITIONS

The vertical down welding technique can be useful when making some types of welds. The major advantages of this technique are the following:

- Speed—Very high rates of travel are possible.
- Shallow penetration—Thin sections or root openings can be welded with little burnthrough.
- Good bead appearance—The weld has a nice width-to-height ratio and is uniform.

Vertical down welds are often used on thin sheet metals or in the root pass in grooved joints. The combination of controlled penetration and higher welding speeds makes vertical down the best choice for such welds. The ease with which welds with a good appearance can be made is deceiving. Generally, more skill is required to make sound welds with this technique than in the vertical up position. The most common problem with these welds is lack of fusion or overlap. To prevent these problems, the arc must be kept at or near the leading edge of the molten weld pool.

PRACTICE 11-10

Stringer Bead at a 45° Vertical Down Angle

Using the same equipment, materials, and setup as listed in Practice 11-3, you will make a vertical down stringer bead on a plate at a 45° inclined angle.

Holding the welding gun at the top of the plate with a slight dragging angle, **Figure 11-35**, will help to increase penetration, hold back the molten weld pool, and improve visibility of the weld. Be sure that your movements along the 12-in. (305-mm) length of plate are unrestricted.

Lower your hood and start the weld. Watch both the leading edge and sides of the molten weld pool for fusion. The leading edge should flow into the base metal, not curl over it. The sides of the molten weld pool should also show

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FIGURE 11-35 Vertical down position.

fusion into the base metal and not be flashed (ragged) along the edges.

The weld may be made with or without a weave pattern. If a weave pattern is used, then it should be a "C" pattern. The "C" should follow the leading edge of the weld. Some changes on the gun angle may help to increase penetration. Experiment with the gun angle as the weld progresses.

Repeat these welds until you have established a rhythm and technique that work well for you. The welds must be straight and uniform and have complete fusion. Turn off the welding machine and shielding gas and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 11-11

Stringer Bead in the Vertical Down Position

Repeat Practice 11-10 and increase the angle of the plate until you have developed the skill to repeatedly make good welds in the vertical down position. The weld bead must be straight and uniform and have complete fusion. Turn off the welding machine and shielding gas and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 11-12

Butt Joint, Lap Joint, and Tee Joint in the Vertical Down Position

Using the same equipment, materials, and setup as listed in Practice 11-3, you will make vertical down welded joints.

Tack weld the pieces of metal together and brace them in position. Using the same technique developed in Practice 11-10, start at the top of the joint and weld down the length of the joint. When the weld is complete, inspect it for discontinuities and make any necessary changes in your technique. Repeat each type of joint as needed until consistently good welds are obtained. Turn off the welding machine and shielding gas and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 11-13

Butt Joint in the Vertical Down Position with 100% Penetration

Using the same equipment, materials, and setup as listed in Practice 11-3, you will make welded joints with 100% weld penetration.

It may be necessary to adjust the root opening to meet the penetration requirements. Repeat the butt weld as needed until consistently good welds are obtained. Turn off the welding machine and shielding gas and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

HORIZONTAL 2G AND 2F POSITIONS

PRACTICE 11-14

Horizontal Stringer Bead at a 45° Angle

Using the same equipment, materials, and setup as listed in Practice 11-3, you will make a horizontal stringer bead on a plate at a 45° reclined angle.

Start at one end with the gun pointed in a slightly upward direction, **Figure 11-36**. You may use a pushing or a dragging gun angle, depending on the current setting and penetration desired. Undercutting along the top edge and overlap along the bottom edge are problems with both gun angles. Careful attention must be given to the manipulation "weave" technique used to overcome these problems.

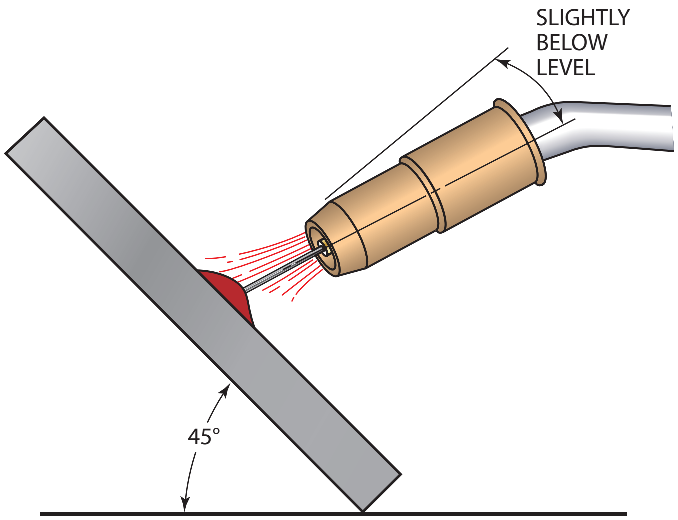

FIGURE 11-36 45° horizontal position.

The most successful weave patterns are the "C" and "J" patterns. The "J" pattern is the most frequently used. The "J" pattern allows weld metal to be deposited along a shelf created by the previous weave, **Figure 11-37**. The length of the "J" can be changed to control the weld bead size. Smaller weld beads are easier to control than large ones.

Repeat these welds until you have established the rhythm and technique that work well for you. The weld must be straight and uniform and have complete fusion. Turn off the welding machine and shielding gas and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

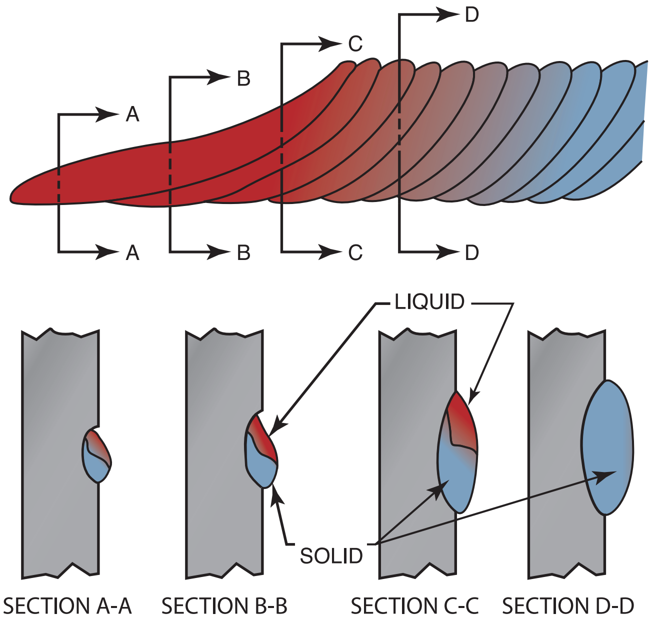

FIGURE 11-37 The actual size of the molten weld pool remains small along the weld.

PRACTICE 11-15

Stringer Bead in the Horizontal Position

Repeat Practice 11-14 and increase the angle of the plate until you have developed the skill to repeatedly make good horizontal welds on a vertical surface. The weld bead must be straight and uniform and have complete fusion. Turn off the welding machine and shielding gas and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 11-16

Butt Joint, Lap Joint, and Tee Joint in the Horizontal Position

Using the same equipment, materials, and setup as listed in Practice 11-3, you will make horizontal welded joints.

Tack weld the pieces of metal together and brace them in position using the same skills developed in Practice 11-14. Starting at one end, make a weld along the entire length of the joint. When making the butt or lap joints, it may help to recline the plates at a 45° angle until you have developed the technique required. Repeat each type of joint as needed until consistently good welds are obtained. Turn off the welding machine and shielding gas and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 11-17

Butt Joint in the Horizontal Position with 100% Penetration

Using the same equipment, materials, and setup as listed in Practice 11-3, you will make overhead joints with 100% penetration in the horizontal position.

It may be necessary to adjust the root opening to meet the penetration requirements. Repeat the butt weld as needed until consistently good welds are obtained. Turn off the welding machine and shielding gas and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

OVERHEAD 4G AND 4F POSITIONS

Following are several advantages for the use of short-circuiting arc metal transfer in the overhead position:

- Small molten weld pool size—The smaller size of the molten weld pool allows surface tension to hold it in place. Less molten weld pool sag results in improved bead contour with less undercut and fewer icicles, **Figure 11-38**.

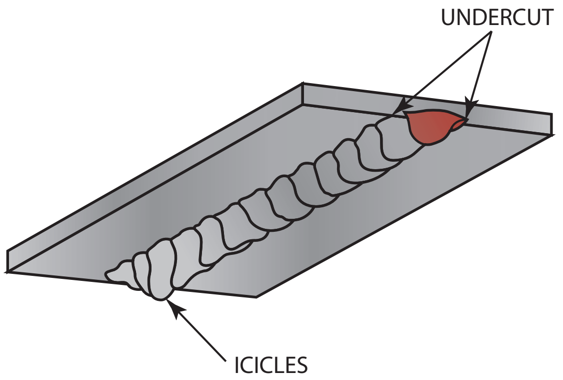

FIGURE 11-38 Overhead weld.

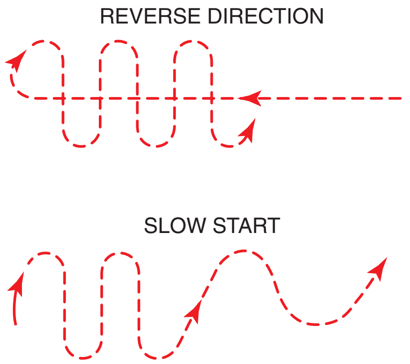

FIGURE 11-39 Two methods of concentrating heat at the beginning of a weld bead to aid in penetration depth.

- Direct metal transfer—The direct metal transfer method does not rely on other forces to get the filler metal into the molten weld pool. This results in efficient metal transfer and less spatter and loss of filler metal.

PRACTICE 11-18

Stringer Bead Overhead Position

Using the same equipment, materials, and setup as listed in Practice 11-3, you will make a welded stringer bead in the overhead position.

The molten weld pool should be kept as small as possible for easier control. A small molten weld pool can be achieved by using lower current settings, by using a longer wire stickout, by traveling faster, or by pushing the molten weld pool. The technique used is the welder's choice. Often a combination of techniques can be used with excellent results.

Lower current settings require closer control of gun manipulation to ensure that the wire is fed into the molten weld pool just behind the leading edge. The low power will cause overlap and more spatter if this wire-to-molten weld pool contact position is not closely maintained.

Faster travel speeds allow the welder to maintain a high production rate even if multiple passes are required to complete the weld. Weld penetration into the base metal at the start of the bead can be obtained by using a slow start or quickly reversing the weld direction. Both the slow start and reversal of weld direction put more heat into the start to increase penetration, **Figure 11-39**. The higher speed also reduces the amount of weld distortion by reducing the amount of time that heat is applied to a joint.

The pushing or trailing gun angle forces the bead to be flatter by spreading it out over a wider area as compared to the bead resulting from a dragging or backhand gun angle. The wider, shallow molten weld pool cools faster, resulting in less time for sagging and the formation of icicles.

When welding overhead, extra personal protection is required to reduce the danger of burns. Leather sleeves or leather jackets and caps should be worn.

Much of the spatter created during overhead welding falls into the shielding gas nozzle. The effectiveness of the shielding gas is reduced, **Figure 11-40**, and the contact tube may short out to the gas nozzle, **Figure 11-41**. Turbulence caused by the spatter obstructing the gas may lead to weld contamination. The shorted gas nozzle may arc to the work, causing damage to the nozzle and to the plate. To control the amount of spatter, a longer stickout and/or a sharper gun-to-plate angle is required to allow most of the spatter to fall clear of the gas nozzle. The nozzle can be dipped, sprayed, or injected automatically, **Figure 11-42**, with anti-spatter to help prevent the spatter from sticking. Applying anti-spatter will not stop the spatter from building up, but it does make its removal much easier.

Make several short weld beads using various techniques to establish the method that is most successful and most comfortable for you. After each weld, stop and evaluate it before making a change. When you have decided on the technique to be used, make a welded stringer bead that is 12 in. (305 mm) long.

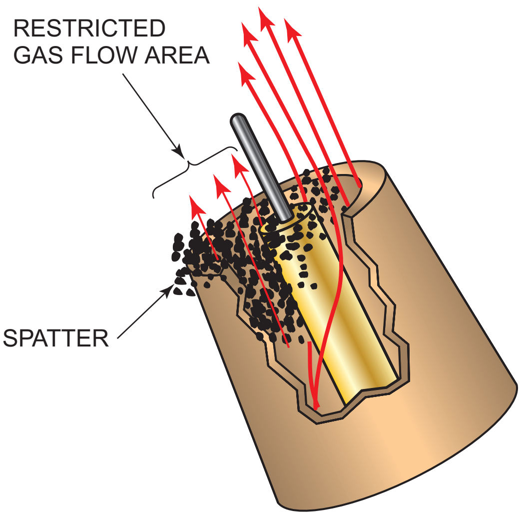

FIGURE 11-40 Shielding gas flow affected by excessive weld spatter in nozzle.

FIGURE 11-41 Gas nozzle damaged after shorting out against the work.

Repeat the weld until it can be made straight, uniform, and free from any visual defects. Turn off the welding machine and shielding gas and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 11-19

Butt Joint, Lap Joint, and Tee Joint in the Overhead Position

Using the same equipment, materials, and setup as listed in Practice 11-3, you will make an overhead welded joint.

Tack weld the pieces of metal together and secure them in the overhead position. Be sure you have an unrestricted view and freedom of movement along the joint. Start at one end and make a weld along the joint. Use the same technique developed in Practice 11-18.

Repeat the weld until it can be made straight, uniform, and free from any visual defects. Turn off the welding machine and shielding gas and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 11-20

Butt Joint in the Overhead Position with 100% Penetration

Using the same equipment, materials, and setup as listed in Practice 11-3, you will make overhead welded joints having 100% penetration.

Tack weld the metal together. It may be necessary to adjust the root opening to allow 100% weld metal penetration. During these welds, it may be necessary to use a dragging or backhand torch angle. When used with a "C" or "J" weave pattern, this torch angle helps to achieve the desired depth of penetration. A key hole just ahead of the molten weld pool is a good sign that the metal is being penetrated, **Figure 11-43**.

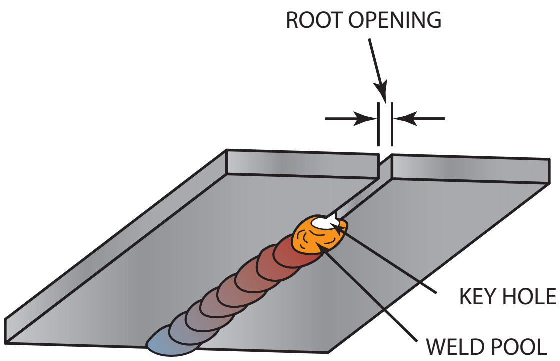

FIGURE 11-43 Overhead welding.

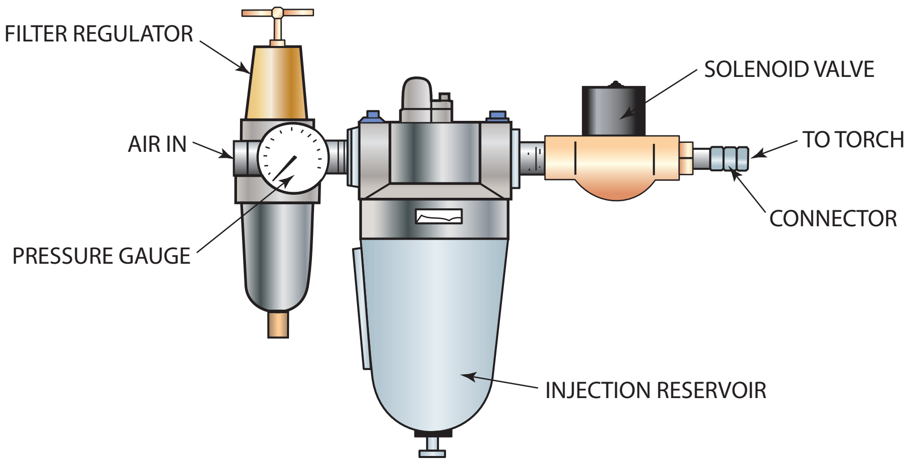

FIGURE 11-42 Automatic anti-spatter system that can be added to a GMA welding gun.

Repeat the butt weld until it can be made straight, uniform, and free from any visual defects. Turn off the welding machine and shielding gas and clean your work area when you are finished welding.

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GLOBULAR METAL TRANSFER, 1G POSITION

PRACTICE 11-21

Stringer Bead

Using a properly set up and adjusted GMA welding machine (see Table 11-11), proper safety protection, 0.035-in. and/or 0.045-in. (0.9-mm and/or 1.2-mm) diameter wire, and two or more pieces of mild steel plate 12 in. (305 mm) long and 1/4 in. (6 mm) thick, make a stringer bead weld in the flat position using the globular metal transfer method.

- Start at one end of the plate and use either a push or drag technique to make a weld bead along the entire 12-in. (305-mm) length of the metal.
- After completing the weld, check its appearance and make any changes needed to correct the weld, **Figure 11-44**.
- Repeat the weld and make additional adjustments as required in the frequency, amplitude, or pulse width.
- After the machine is set, start working on improving the straightness and uniformity of the weld.

The location of the arc in the molten weld pool is not as critical in this method of metal transfer as it is in the short-circuiting arc method. If the arc is too far back on the molten weld pool, however, fusion along the leading edge may be reduced, **Figure 11-45**. Moving the arc to the cool metal ahead of the molten weld pool often causes an increase in spatter.

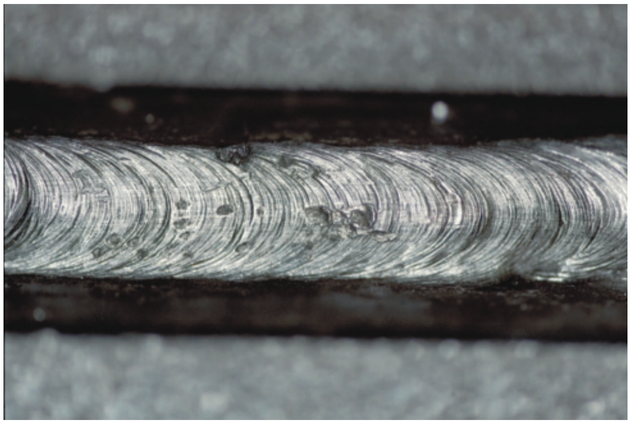

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FIGURE 11-44 Weld bead made with GMAW globular metal transfer mode.

The weave pattern selected should allow the arc to follow the leading edge of the molten weld pool if deep penetration is needed. A pattern that moves the arc back from the leading edge completely or in part results in reduced penetration.

Repeat the weld until it can be made straight, uniform, and free from any visual defects. Turn off the welding machine and shielding gas and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 11-22

Butt Joint

Using the same equipment, materials, and setup as listed in Practice 11-21, you will make a welded joint in the flat position, **Figure 11-46**.

The heat produced during GMA welding is not enough to force 100% penetration consistently through metal thicker than 3/16 in. (4.8 mm). On occasion, or with extra effort, it is possible to obtain 100% penetration. However, the method generally is not reliable enough for most industrial applications. To ensure that the joint is completely fused, it is prepared for welding with a groove. Any one of several groove designs can be used, **Figure 11-47**. The V-groove is most frequently used because of the ease with which it can be produced.

The V-groove should be made with a 45° inclined angle, **Figure 11-48**. The small diameter filler metal allows the usual 60% inclined angle for SMAW to be reduced. This reduced groove size requires less filler metal and can be welded in less time, resulting in lower cost.

After the metal has been grooved, tack weld it together. The root opening between the plates should be 1/8 in. (3 mm) or less. Starting at one end, make a single pass weld along the entire joint. A weave pattern that follows the contour of the groove should be used to ensure complete fusion, **Figure 11-49**.

The completed weld should be uniform in width and reinforcement and have no visual defects. Repeat the weld until it can be made straight, uniform, and free from any visual defects. Turn off the welding machine and shielding gas and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 11-23

Butt Joint with 100% Penetration

Using the same equipment, materials, and setup as listed in Practice 11-22, you will make a groove weld with 100% penetration.

Using the technique developed in Practice 11-22 and making the necessary adjustments in the root gap, the weld

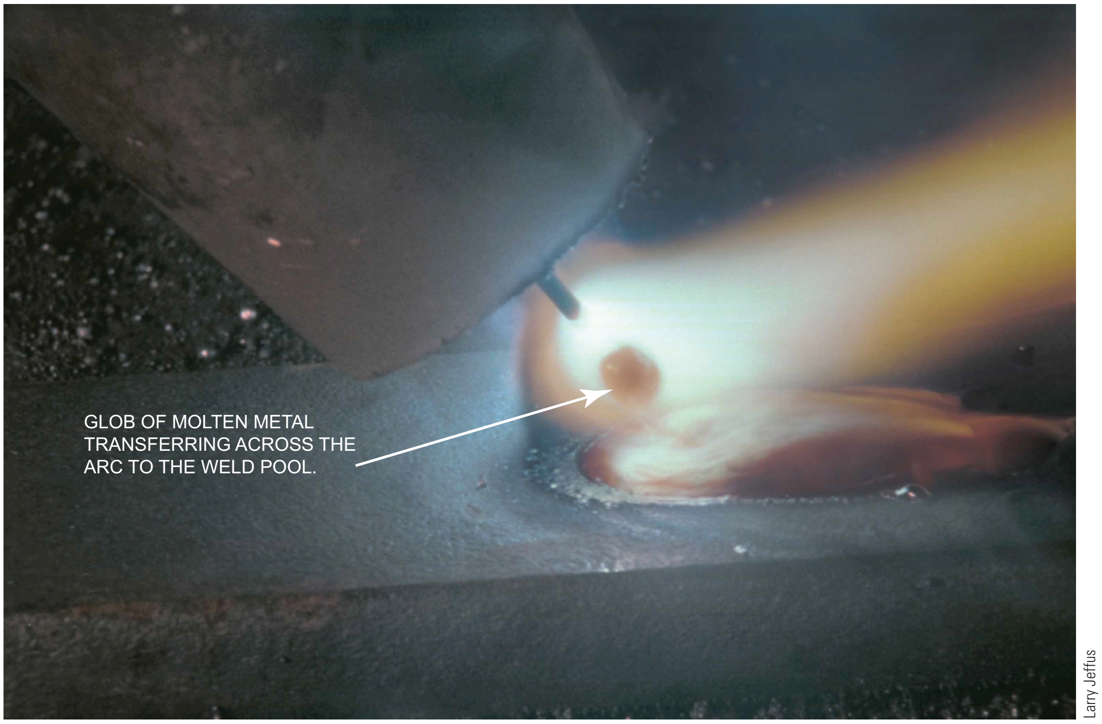

FIGURE 11-45 Molten globule of metal being transferred across the arc.

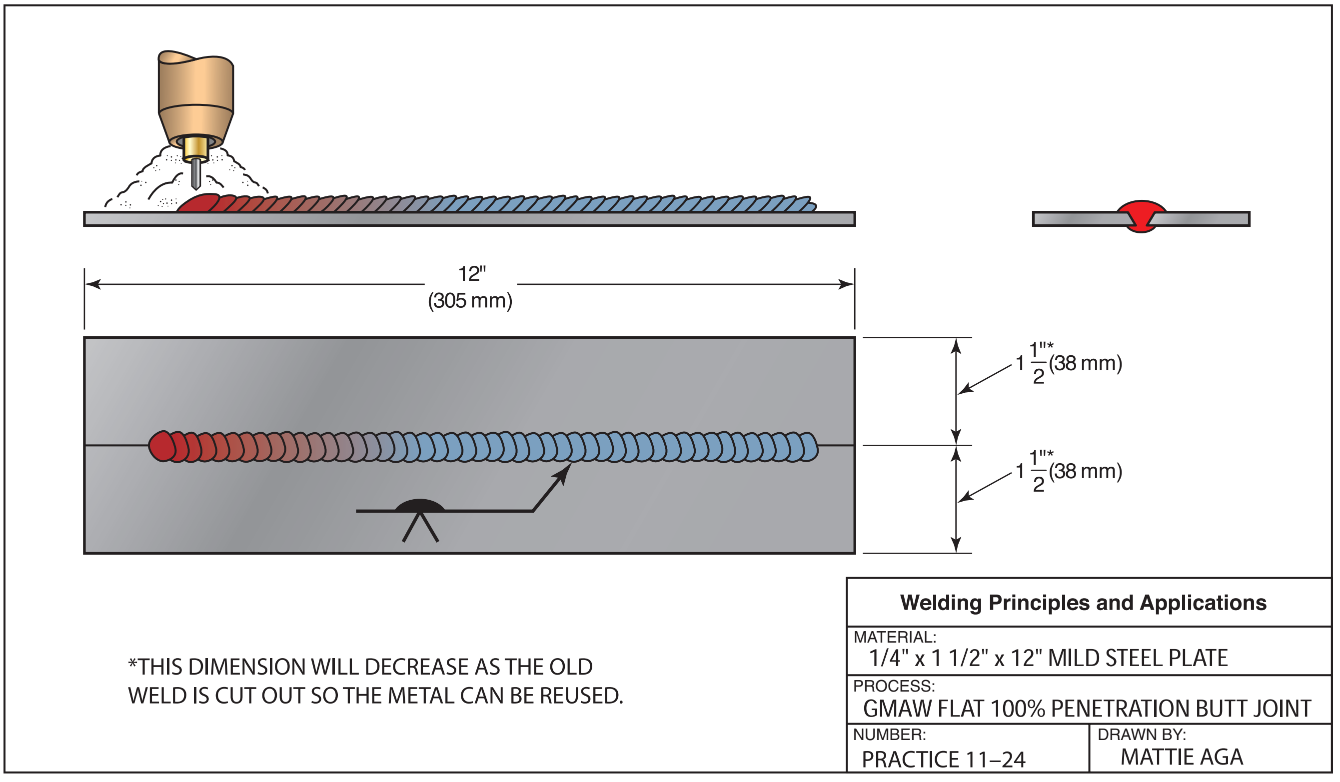

FIGURE 11-46 Single V-groove butt joint in the flat position.

metal must fuse 100% of the plate thickness. Watch the molten weld pool. If it appears to sink or does not increase in size, you are probably burning through. This action will cause excessive root penetration. To correct this problem, speed up the travel rate and/or increase the contact tube-to-work distance.

After the weld is complete, inspect the root surface for the proper appearance. Repeat the weld until it can be made straight, uniform, and free from any visual defects. Turn off the welding machine and shielding gas and clean your work area when you are finished welding.

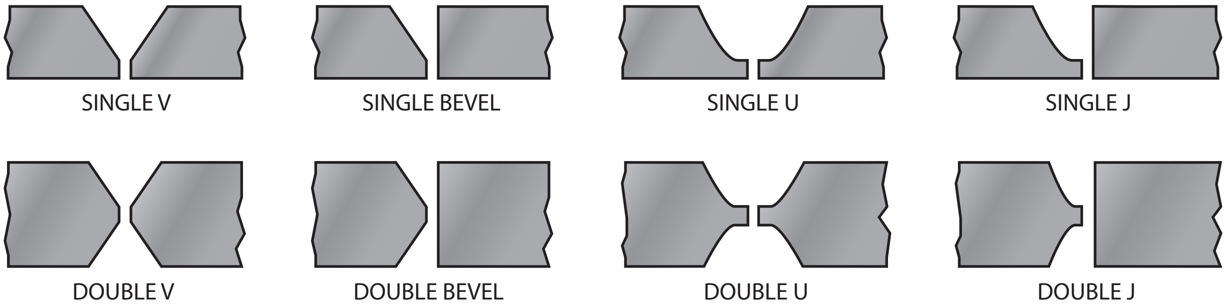

FIGURE 11-47 Typical groove designs.

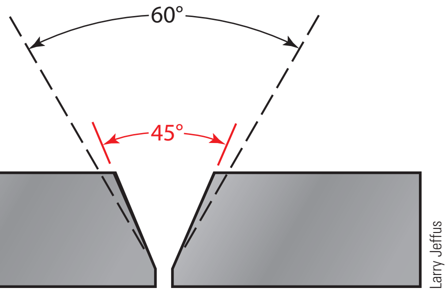

FIGURE 11-48 A smaller groove angle reduces both weld time and filler metal required to make the weld.

FIGURE 11-49 Uniform weld produced with a weave pattern.

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PRACTICE 11-24

Tee Joint and Lap Joint in the IF Position

Using the same equipment, materials, and setup as listed in Practice 11-22, you will make a fillet weld in the flat position.

It is not necessary to groove the plates used for a tee or lap joint to obtain a sound weld. Fillet weld strength can be obtained by making the weld the proper size for the plate thickness.

The face or surface of a fillet weld should be as flat as possible. Welds with excessive buildup will waste metal. Welds with too little buildup will be weak, flat, or concave. Fillet weld beads have fewer stress points to cause weld failure during cyclical loading.

A weave pattern that follows the contour of the joint should be used to ensure adequate fusion, **Figure 11-50**. Repeat the weld until it can be made straight, uniform, and free from any visual defects. Turn off the welding machine and shielding gas and clean your work area when you are finished welding.

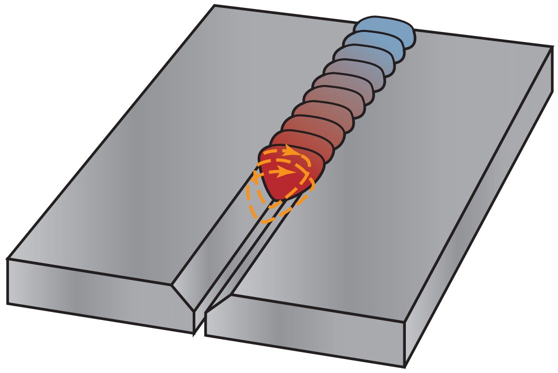

FIGURE 11-50 The electrode should be moved along the groove contour.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 11-25

Tee Joint and Lap Joint in the 2F Position

Using the same equipment, materials, and setup as listed in Practice 11-22, you will make a fillet weld in the horizontal position.

Tack weld the metal together and place the assembly in the horizontal position. The globular pulsed-arc metal transfer method can be used for a horizontal weld. However, care must be taken to ensure that the legs of the fillet are equal. Because of the size and fluidity of the molten weld pool, undercutting along the top edge and overlap along the bottom edge can also be problems.

To control or eliminate these defects, the beads must be small and quickly made. In addition, a proper weave pattern must be established. The pattern must follow the plate surfaces and establish a shelf to support the weld. After the weld is complete, inspect it for defects and measure it for uniformity. Repeat the weld until it can be made straight, uniform, and free from any visual defects. Turn off the welding machine and shielding gas and clean your work area when you are finished welding.

Process	Wire Diameter	Amperage Range	Voltage Range	Shielding Gas
Axial spray	0.030	115-200	15-27	98% Ar + 2% O_2
	0.035	165-300	18-32	
	0.045	200-450	20-34	

TABLE 11-12 Typical Welding Current Settings for Axial Spray Metal Transfer for Mild Steel

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

AXIAL SPRAY

PRACTICE 11-26

Stringer Bead, 1G Position

Using a properly set-up and adjusted GMA welding machine (see **Table 11-12**), proper safety protection, 0.035-in. and/or 0.045-in. diameter (0.9-mm and/or 1.2-mm) wire, and two or more pieces of mild steel plate 12 in. (305 mm) long and 1/4 in. (6 mm) thick, you will make a welded stringer bead in the flat position.

Start at one end of the plate and use either a push or drag technique to make a weld bead along the entire 12-in. (305-mm) length of the metal using spray or pulsed-arc metal transfer. After the weld is complete, check its appearance and make any changes needed to correct the weld, **Figure 11-51**. Repeat the weld and make any additional adjustments required. After the machine is set, start working on improving the straightness and uniformity of the weld. Turn off the welding machine and shielding gas and clean your work area when you are finished welding.

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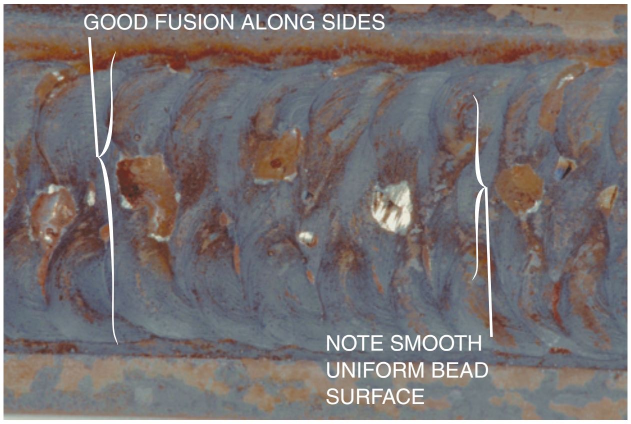

FIGURE 11-51 Weld bead made with GMAW axial spray metal transfer.

PRACTICE 11-27

Butt Joint, Lap Joint, and Tee Joint Using the Axial Spray Method

Using the same equipment, materials, and setup as listed in Practice 11-26, you will make a flat and horizontal weld using axial spray or pulsed axial spray metal transfer, **Figure 11-52**.

Tack weld the metal together and place the assembly in the flat position on the welding table. Start at one end and make a uniform weld along the entire 12-in. (305-mm) length of the joint. Watch the sides of the fillet weld for signs of undercutting.

Repeat the weld until it can be made straight, uniform, and free from any visual defects. Turn off the welding machine and shielding gas and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 11-28

Butt Joint and Tee Joint

Using the same equipment, materials, and setup as listed in Practice 11-27, you will make a flat weld using axial spray metal transfer. Each weld must pass the guided-bend test. Repeat each type of weld joint as needed until the bend test can be passed. Turn off the welding machine and shielding gas and clean your work area when you are finished welding.

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FIGURE 11-52 GMAW axial spray metal transfer.

Summary

Slight changes in welding gun angle and electrode extension can make significant differences in the quality of the weld produced. As a new welder you might find it difficult to tell the effect of these changes if they are slight. Therefore, as you start to learn this process it is a good idea to make more radical changes so it is easier for you to see their effects on the weld. Later, as you develop your skills you can use these slight changes to aid in controlling the weld's quality and appearance as it progresses along the joint. Small adjustments in your welding technique are required to compensate for slight changes that occur along a welding joint, such as joint gap and the increasing temperature of the base metal.

Variations in conditions can significantly affect welding setup for the GMA process. Before starting an actual weld in the field you should practice to test your setup. Practice on scrap metal of a similar thickness and type of metal to be welded. A practice weld before you begin welding can significantly increase the chances that your weld will meet standards or specifications. Making these sample or test welds is more important when you are welding in the field because welds outside of the shop are more difficult to control and anticipate. Think of this as when an athlete warms up before competing.

You will find it beneficial when you are initially setting up your welder to have another welder assist you by making changes in the welding machine's settings as you are welding. This teamwork can significantly increase your setup accuracy and reduce setup time. Later in the field, having developed a keen eye for watching the weld, you can then make these adjustments for yourself more rapidly and accurately. Working with another student in a group effort like this will also give you a better understanding of how other individuals' setup preferences affect their welds. Welding is an art; therefore, each welder may have slight differences in preference for voltage, amperage, gas flow, and other setup variables. This gives you an opportunity to learn more from others.

Review

1. What items make up a basic semiautomatic welding system?
2. What must be done to the shielding gas cylinder before the valve protection cap is removed?
3. Why is the shielding gas valve "cracked" before the flowmeter regulator is attached?
4. What causes the electrode to bird-nest?
5. Why must all fittings and connections be tight?
6. What parts should be activated by depressing the gun switch?
7. What benefit does a welding wire's cast provide?
8. What are the advantages of using a feed roller pressure that is as light as possible?
9. Why should the feed roller drag prevent the spool from coasting to a stop when the feed stops?
10. Why must you always wind the wire tightly into a ball or cut it into short lengths before discarding it in the proper waste container?
11. How is the amperage adjusted on a GMA welder?
12. What effect on the welding current does increasing the wire-feed speed have?
13. Using Table 11-1, determine the amperage if 400 ipm (10.2 m/min) of 0.45-in. (1.2-mm) steel wire is fed in 1 minute.
14. What happens to the weld as the electrode extension is lengthened?
15. What is the effect on the weld of changing the welding angle from a dragging to a pushing angle?
16. What are the advantages of adding oxygen or CO_2 to argon for welds on steel?
17. What reactive gases are used with argon for GMA welding on steels?
18. What are the advantages of using CO_2 for making GMA welds on steel?
19. What is mill scale?
20. What type of porosity is most often caused by mill scale?
21. What should the welder watch if the view of the weld is obstructed by the shielding gas nozzle?
22. When making a vertical weld and it appears that the weld metal is going to drip over the shelf, what should you do?
23. What are the advantages of making vertical down welds?
24. How can small weld beads be maintained during overhead welds?
25. How can spatter be controlled on the nozzle when making overhead welds?

Chapter 12

Flux Cored Arc Welding Equipment, Setup, and Operation

OBJECTIVES

After completing this chapter, the student should be able to

- explain the FCA welding process.
- describe what equipment is needed for FCA welding.
- list the advantages of FCA welding and explain its limitations.
- tell how electrodes are manufactured and explain the purpose of the electrode cast and helix.
- discuss what flux can provide to the weld and how fluxes are classified.
- explain what each of the digits in a standard FCAW electrode identification number means.
- describe the proper care and handling of FCAW electrodes.
- list the common shielding gases used and explain their benefits.
- explain how changing the welding gun angle affects the weld produced.
- identify the methods of metal transfer and describe each.
- explain the effect electrode extension has on FCA welding.
- tell what can cause weld porosity and how it can be prevented.

KEY TERMS

air-cooled gun
carbon
coils
deoxidizers
dual shield
flux cored arc welding (FCAW)
forehand
lime-based flux
rutile-based flux
self-shielding
slag
smoke extraction nozzle
spools
water-cooled gun

INTRODUCTION

Flux cored arc welding (FCAW) is a fusion welding process in which weld heating is produced from an arc between the work and a continuously fed filler metal electrode. Atmospheric shielding can be provided completely by the flux material FCAW-S or in part by the flux cored material with an external shielding gas FCAW-G, **Figure 12-1**. Extra shielding may or may not be supplied through a nozzle in the same way as in GMAW.

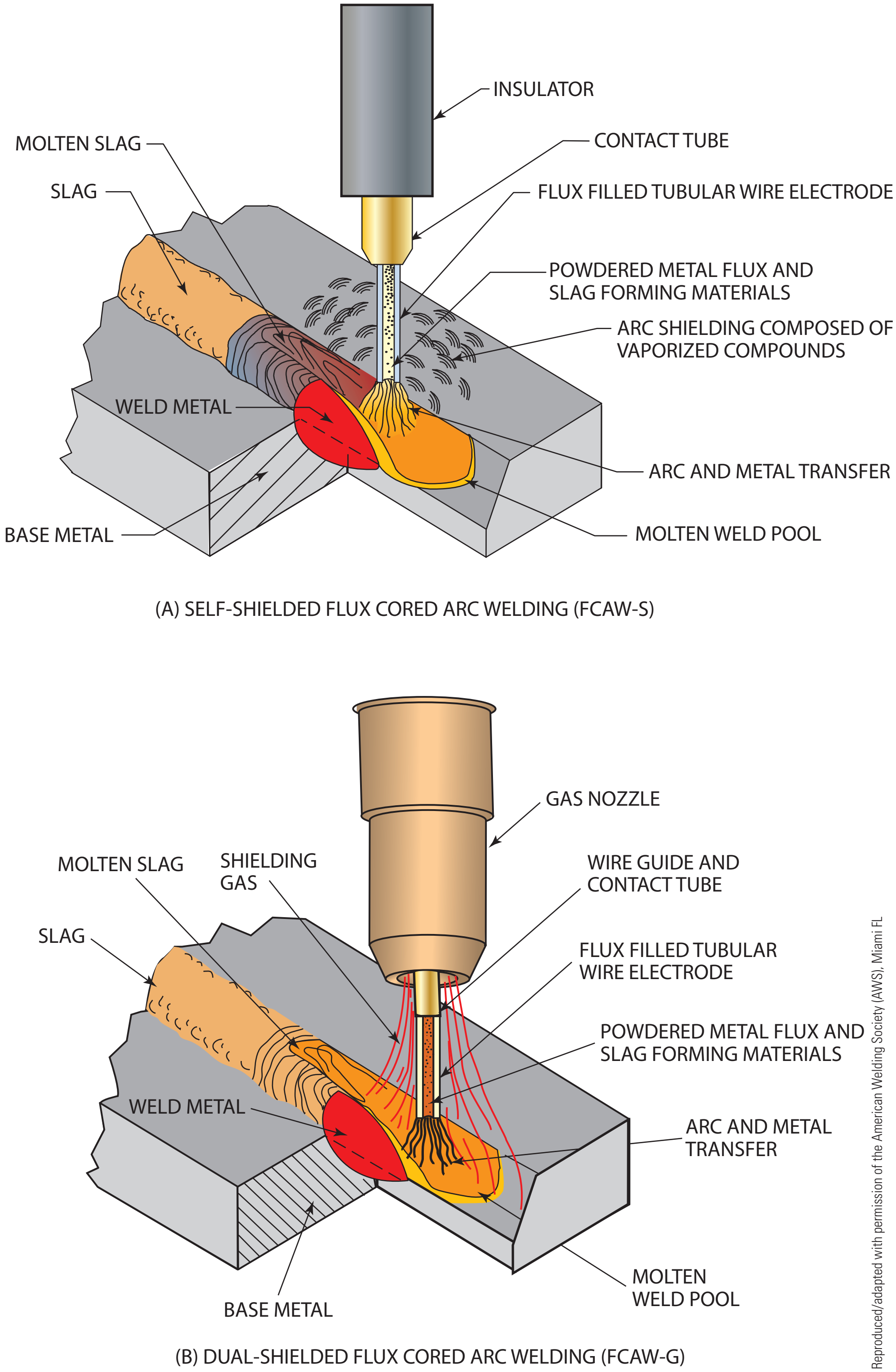


FIGURE 12-1 (A) Self-shielded flux cored arc welding; (B) dual-shielded flux cored arc welding.

The self-shielding flux of FCAW-S makes it the best choice for making welds outdoors or in windy conditions where the gas shielding of FCAW-G might be blown away. In addition, the fact that FCAW-S does not need the shielding gas cylinder makes it more portable.

By having an external shielding gas, FCAW-G electrodes can have more allowing elements and fluxing agents added to the flux core because not as much gas-forming elements are needed.

Although the process was introduced in the 1950s, it represented less than 5% of the total amount of welding done in 1965. In 2005, it passed the 50% mark for filler metal usage. Its popularity continues to rise because of a number of factors. Improvements in the fluxes, availability of smaller diameter electrodes, reliability of the equipment, better electrode feed systems, and improved guns have all led to the increased usage. Guns equipped with electronic controls that allow the welder to remotely adjust the welding parameters and onboard computers with preprogrammed welding procedures for virtually any thickness, joint design, material, and position that a welder might encounter are the latest in a long line of improvements to this process, **Figure 12-2**.

FIGURE 12-2 (A) FCA welding without smoke extraction and (B) with smoke extraction. (C) Typical FCAW smoke extraction gun. (D) Typical smoke exhaust system.

PRINCIPLES OF OPERATION

FCA welding is similar to GMA welding in a number of ways, **Figure 12-3**. Both processes use a constant-potential (CP) or constant-voltage (CV) power supply. ***Constant-potential*** and ***voltage*** are terms that have the same meaning. CP welders supply voltage (potential) to the welding electrode, which can be controlled by an adjusting knob on the welder. The arc voltage directly affects the arc length. Increasing the voltage increases the arc length and lowering the voltage shortens the arc length.

Because the arc voltage remains constant, changes in the wire-feed speed will automatically cause a change in the amperage to keep the arc voltage constant. A stick welder is a constant current (CC) type of machine. When an electrode is accidently stuck to the work, the current is limited to the machine's present amperage setting. However, on a CP welding machine 100% of the machine's maximum amperage is always available. We never want to short out any welding machine, but if it were possible to accidently stick the FCA welding electrode, the amperage would instantly surge to the machine's maximum.

The CP welding machine's amperage naturally increases to whatever level is needed to maintain the same arc length. Therefore, as the wire feed increases the amperage increases, and if the wire-feed speed is lowered, the amperage decreases automatically. If the wire-feed speed were left the same and a larger diameter wire were installed, then the amperage would be higher because it takes more amperage to melt off the end of the wire to keep the voltage constant. Of course, installing a smaller wire would have the opposite effect on the amperage.

The effects on the weld of electrode extension, gun angle, welding direction, travel speed, and other welder manipulations are similar to those experienced in GMA welding. As in GMA welding, having a correctly set welder does not ensure a good weld. The skill of the welder is an important factor in producing high-quality welds.

The flux inside the electrode provides the molten weld pool with protection from the atmosphere, improves strength through chemical reactions and alloys, and improves the weld shape.

Atmospheric contamination of molten weld metal occurs as it travels across the arc gap and within the pool before it solidifies. The major atmospheric contaminations come from oxygen and nitrogen, the major elements in air. The addition of fluxing and gas-forming elements to the core electrode reduces or eliminates their effects.

Improved strength and other physical or corrosive properties of the finished weld are improved by the flux. Small additions of alloying elements, deoxidizers, and gas-forming and slag agents can all improve the desired weld properties. **Carbon**, chromium, and vanadium can be added to improve hardness, strength, creep resistance, and corrosion resistance. Aluminum, silicon, and titanium all help remove oxides and/or nitrides in the weld. Potassium, sodium, and zirconium are added to the flux and form a slag.

A complete listing of weld metal additives and flux elements and their effects on the weld can be found in Chapter 25 (Welding Metallurgy) and Chapter 27 (Filler Metal Selection).

FLUX CORE

The flux core additives that serve as deoxidizers, gas formers, and slag formers either protect the molten weld pool or help to remove impurities from the base metal. Deoxidizers may convert small amounts of surface oxides like mill scale back into pure metal. They work much like the elements used to refine iron ore into steel.

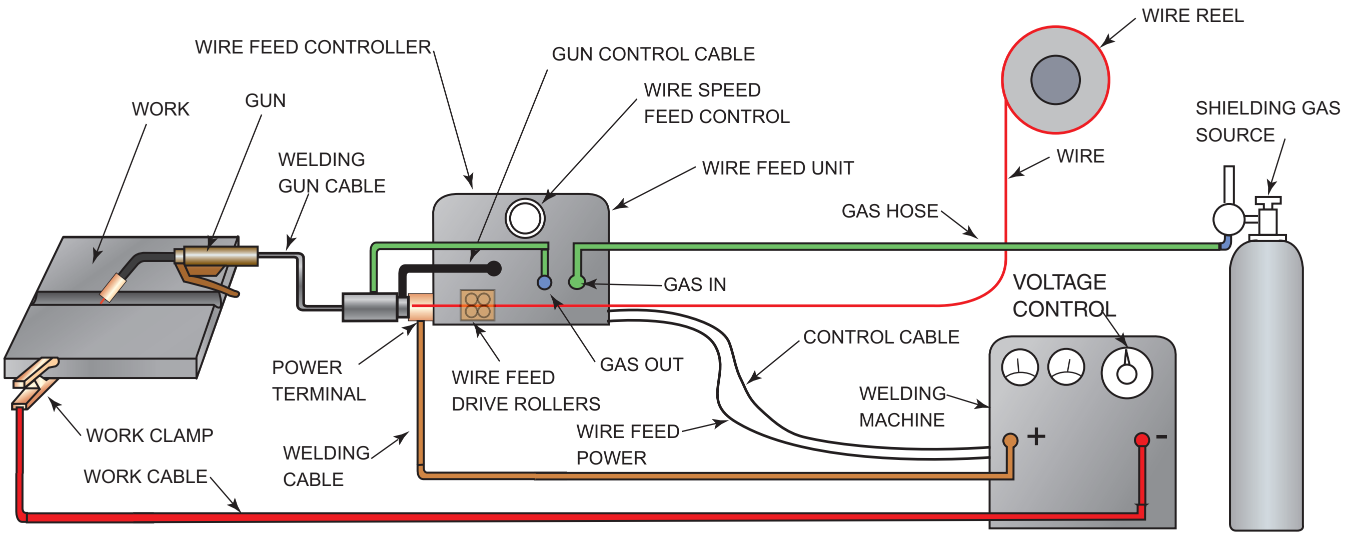


FIGURE 12-3 Large capacity wire-feed unit can be used with FCAW or GMAW.

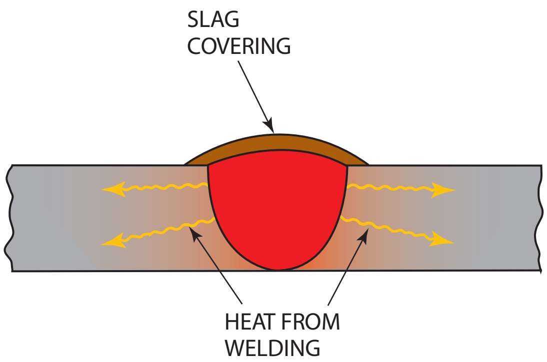


FIGURE 12-4 The slag covering keeps the welding heat from escaping quickly, thus slowing the cooling rate.

Gas Formers

Some elements in the flux that rapidly expand, called gas formers, push the surrounding air away from the molten weld pool. If oxygen in the air were to come in contact with the molten weld metal, then the weld metal would quickly oxidize. Sometimes this can be seen at the end of a weld when the molten weld metal erupts in a shower of tiny sparks.

Slag

The slag covering of the weld is useful for several reasons. **Slag** helps the weld by protecting the hot metal from the effects of the atmosphere, controlling the bead shape by serving as a dam or mold, and serving as a blanket to slow the weld's cooling rate, which improves its physical properties, **Figure 12-4**.

EQUIPMENT

Power Supply

The FCA welding power supply is the same type that is required for GMAW, called constant-potential, constant-voltage (CP, CV). The words *potential* and *voltage* have the same electrical meaning and are used interchangeably. FCAW machines can be much more powerful than GMAW machines and are available with up to 1500 amperes of welding power.

FCA Welding Guns

FCA welding guns are available as **water-cooled guns** or **air-cooled guns**, **Figure 12-5**. Although most of the FCA welding guns that you will find in schools are air-cooled, our industry often needs water-cooled guns because of the higher heat caused by longer welds made at higher currents. The water-cooled FCA welding gun is more efficient than an air-cooled gun at removing waste heat. The air-cooled gun is more portable because it has fewer hoses, and it may be made lighter so it is easier to manipulate than the water-cooled gun.

Also, the water-cooled gun requires a water reservoir or another system to provide the needed cooling. There are two major ways that water can be supplied to the gun for cooling. Cooling water can be supplied directly from the building's water system, or it can be supplied from a recirculation system.

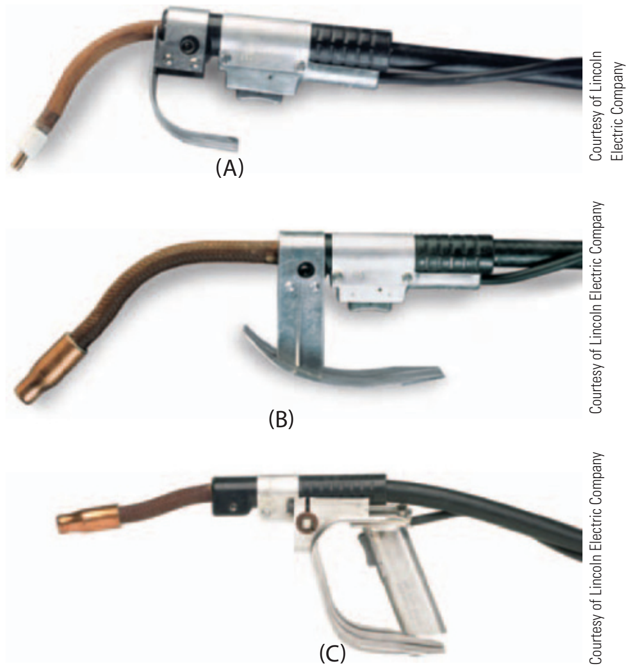


FIGURE 12-5 Typical FCA welding guns: (A) 350 ampere rating self-shielding, (B) 450 ampere rating gas-shielding, and (C) 600 ampere rating gas-shielding.

Most welding companies are going away from welding systems that use cooling water supplied directly from the building's water system and dumped into a wastewater drain once it has passed through the gun. When this type of a system is used, a pressure regulator must be installed to prevent pressures that are too high from damaging the hoses. Water pressures higher than 35 psi (241 kg/mm^2) may cause the water hoses to burst. Check valves must also be installed in the supply line to prevent contaminated water from being drawn back into the water supply.

Recirculating cooling water systems eliminate any of the problems associated with open systems. Chemicals may be added to the water in recirculating systems to prevent freezing, to aid in pump lubrication, and to prevent algae growth. Only manufacturer-approved additives should be used in a recirculation system. Read all of the manufacturer's safety and data sheets before using these chemicals.

THINK GREEN

Conserve Water

Recirculating cooling water for FCA welding torches is important for water conservation. Some cities and states have laws that restrict the use of open systems because of the need for water conservation. Check with your city or state for any restrictions before installing an open water-cooling system.

Fume Extraction Nozzles Because of the large quantity of fumes that can be generated during FCA welding, Figure 12-2A, fume removal guns have been designed, Figure 12-2B. These systems use a vacuum to pull the smoke back into a specially designed **smoke extraction nozzle** on the welding gun. The disadvantage of having a slightly heavier gun is offset by the system's advantages. The advantages of the system are as follows:

- Cleaner air for the welder to breathe because the smoke is removed before it rises to the welder's face.
- Reduced heating and cooling cost because the smoke is concentrated, so less shop air must be removed with the smoke.

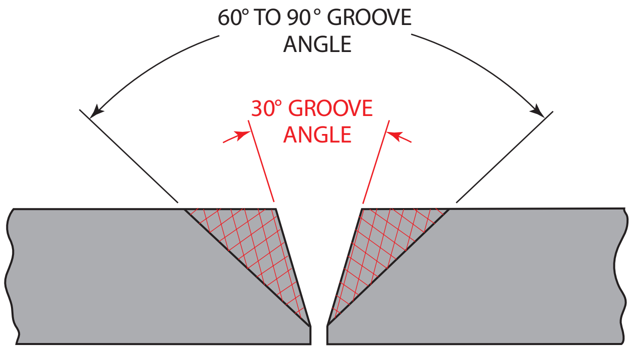


FIGURE 12-6 The narrower groove angle for FCAW saves on filler metal, welding time, and heat input into the part.

Electrode Feed

Electrode feed systems are similar to those used for GMAW. The major difference is that larger FCAW machines that can use large diameter wire most often have two sets of feed rollers. The two sets of rollers help reduce the drive pressure on the electrode. Excessive pressure can distort the electrode wire diameter, which can allow some flux to be dropped inside the electrode guide tube.

ADVANTAGES

FCA welding offers the welding industry a number of important advantages.

High Deposition Rate High rates of depositing weld metal are possible. FCA welding deposition rates of more than 25 lb/hr (12 kg/hr) of weld metal are possible. This compares to approximately 10 lb/hr (6 kg/hr) for SMA welding using a very large diameter electrode of 1/4 in. (6 mm).

Minimum Electrode Waste The FCA method makes efficient use of filler metal; between 75% and 90% of the weight of the FCAW electrode is metal, and the remainder is flux. SMAW electrodes have a maximum of 75% filler metal; some SMAW electrodes have much less. Also, a stub must be left at the end of each SMA welding electrode. The stub will average 2 in. (51 mm) in length, resulting in a loss of 11% or more of the SMAW filler electrode purchased. FCA welding has no stub loss, so nearly 100% of the FCAW electrode purchased is used.

Narrow Groove Angle Because of the deep penetration characteristic, no edge-beveling preparation is required on some joints in metal up to 1/2 in. (13 mm) in thickness. When bevels are cut, the joint-included angle can be reduced to as small as 35°, **Figure 12-6**. The reduced groove angle results in a smaller-sized weld. This can save 50% of filler metal with approximately the same savings in time and weld power used.

Minimum Precleaning The addition of **deoxidizers** and other fluxing agents permits high-quality welds to be made on plates with light surface oxides and mill scale. This eliminates most of the precleaning required before GMA welding can be performed. Often it is possible to make excellent welds on plates in the "as-cut" condition; no cleanup is needed.

All-Position Welding Small diameter electrode sizes in combination with special fluxes allow excellent welds in all positions. The slags produced assist in supporting the weld metal. This process is easy to use and, when properly adjusted, it is much easier to use than other all-position arc welding processes.

Flexibility Changes in power settings can permit welding to be made on thin-gauge sheet metals or thicker plates using the same electrode size. Multipass welds allow joining unlimited thickness metals. This, too, is attainable with one size of electrode.

High Quality Many codes permit welds to be made using FCAW. The addition of the flux gives the process the high level of reliability needed for welding on boilers, pressure vessels, and structural steel.

Excellent Control The molten weld pool is more easily controlled with FCAW than with GMAW. The surface appearance is smooth and uniform even with less operator skill. Visibility is improved by removing the nozzle when using self-shielded electrodes.

THINK GREEN

FCA Welding Can Save Materials, Energy, and Time

The reduced groove angle will save weld metal, electrical energy, and time as compared to most other welding processes. In addition, the higher deposition rates and minimum electrode waste save manufacturing time and energy. FCA welding will help you work faster and more efficiently.

LIMITATIONS

Ferrous Alloys A limitation of flux cored arc welding is that it is confined to ferrous metals, nickel-based alloys, and some hardfacing electrodes. Generally, all low-and medium-carbon steels and some low-alloy steels, cast irons, and a limited number of stainless steels are presently weldable using FCAW.

Cost of Filler Metals The equipment and electrodes used for the FCAW process are more expensive. However, the cost is quickly recoverable through higher productivity.

Slag Cleanup The removal of postweld slag requires another production step. The flux must be removed before the weldment is finished (painted) to prevent crevice corrosion.

Increased Fumes With the increased welding output comes an increase in smoke and fume generation. The existing ventilation system in a shop might need to be increased to handle the added volume.

FCAW ELECTRODES

FCA welding electrodes are available as seamed-type and seamless-type electrodes. Both types have tightly packed flux inside a metal outer covering. They differ in the way they are manufactured but have little if any difference in the way they weld. Seamless electrode flux cores are less likely to absorb moisture than the seamed electrode.

Methods of Manufacturing The electrodes have flux tightly packed inside. Seamed electrodes are made by first forming a thin sheet of metal into a U-shape, **Figure 12-7**. Then, a measured quantity of flux is poured into the U-shape before it is squeezed shut. It is then passed through a series of dies to size it and further compact the flux.

Seamless electrodes start with a seamless tube. The tube is usually approximately 1 in. (25 mm) in diameter. One end of the tube is sealed, and the flux powder is poured into the open end. The tube is vibrated during the filling process to ensure that it fills completely. Once the tube is full, the open end is sealed. The tube is now sized using a series of dies, **Figure 12-8**.

In both these methods of manufacturing the electrode, the sheet and tube are made up of the desired alloy. Also, in both cases the flux is compacted inside the metal skin. This compacting helps make the electrode operate smoother and more consistently.

Electrode Diameters Electrodes are available in sizes from 0.023 in. to 5/32 in. (0.58 mm to 3.9 mm) in diameter. Smaller diameter electrodes are much more expensive per pound than the same type in a larger diameter. Larger diameter electrodes produce such large welds they cannot be controlled in all positions. The most popular diameters range from 0.035 in. to 3/32 in. (0.9 mm to 2.3 mm).

Filler Metal Packaging The finished FCA filler metal is packaged in a number of forms for purchase by the end user. The electrode wire is wound (rolled) on spools, reels, and coils made from metal, wood, pressed fiber, or plastic, **Figure 12-9**. All of these are collectively called the electrode package. Sometimes drums are used with the wire coiled inside of the drum, **Table 12-1**. The American Welding Society (AWS) has a standard for the size of each of the package units. Although the dimensions of the packages are standard, the weight of filler wire is not standard. More of the smaller diameter wire can fit into the same space than a larger diameter wire, so a package of 0.030 in. (0.8 mm) wire weighs more than the same-sized package of 3/32 in. (2.3 mm) wire.

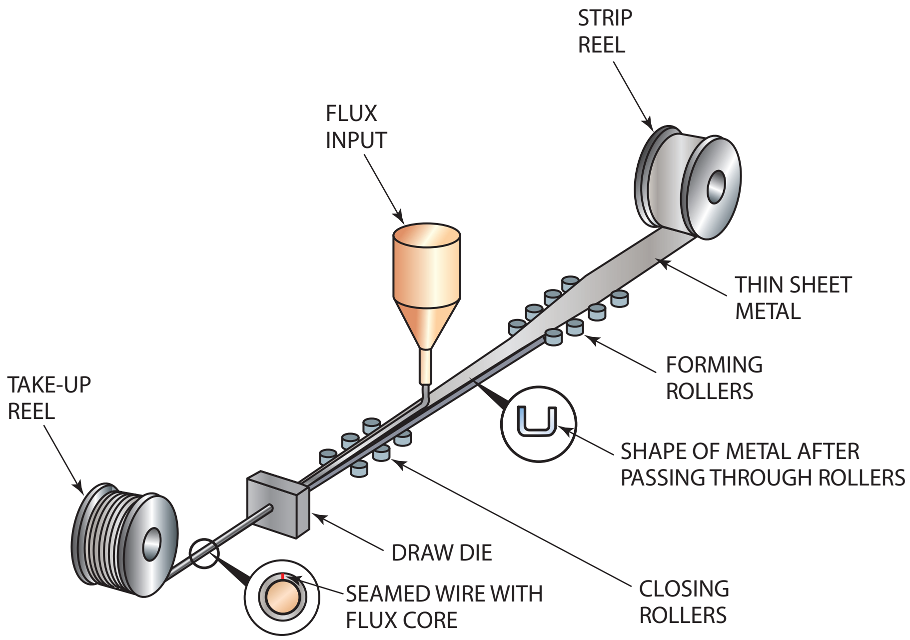


FIGURE 12-7 Putting the flux in the flux-cored wire.

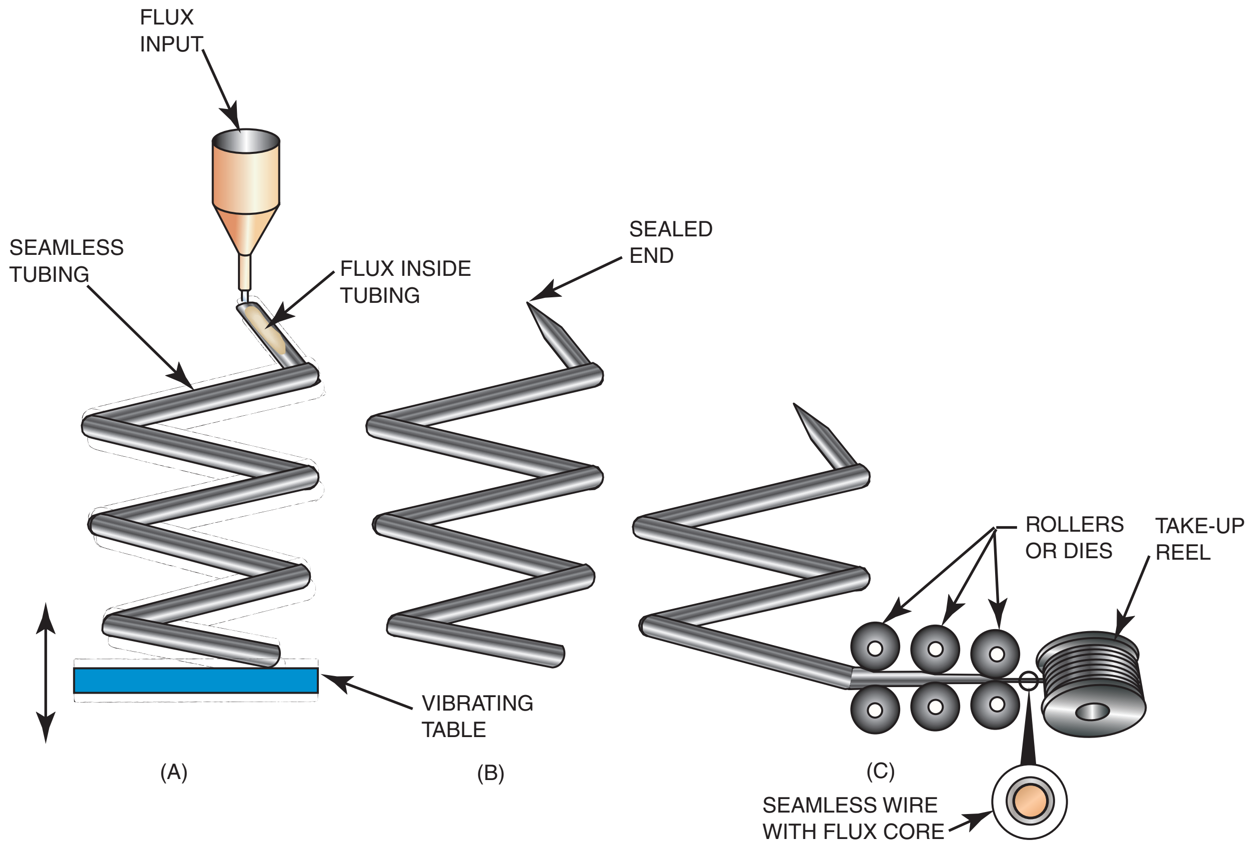
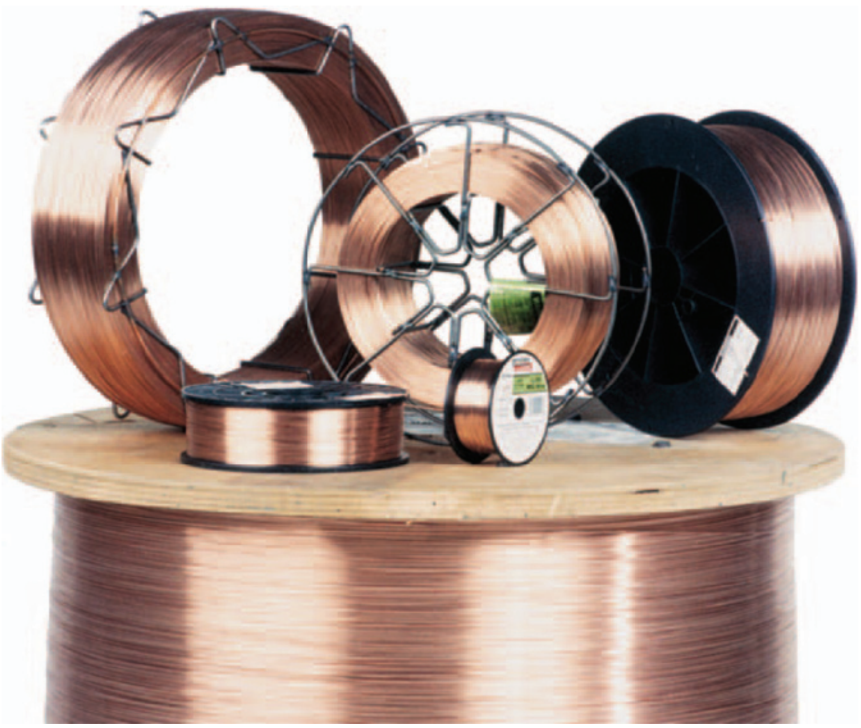


FIGURE 12-8 This shows one method of filling seamless FCA welding filler metal with flux. The vibration helps compact the granular flux inside the tube.



Courtesy of Lincoln Electric Company

FIGURE 12-9 FCAW filler metal weights are approximate. They will vary by alloy and manufacturer.

Packaging	Outside Diameter	Width	Arbor (Hole) Diameter
Spools	4 in. (102 mm)	1 3/4 in. (44.5 mm)	5/8 in. (16 mm)
	8 in. (203 mm)	2 1/4 in. (57 mm)	2 1/16 in. (52.3 mm)
	12 in. (305 mm)	4 in. (102 mm)	2 1/16 in. (52.3 mm)
	14 in. (356 mm)	4 in. (102 mm)	2 1/16 in. (52.3 mm)
Reels	22 in. (559 mm)	12 1/2 in. (318 mm)	1 5/16 in. (33.3 mm)
	30 in. (762 mm)	16 in. (406 mm)	1 5/16 in. (33.3 mm)
Coils	16 1/4 in. (413 mm)	4 in. (102 mm)	12 in. (305 mm)
	Outside Diameter	**Inside Diameter**	**Height**
Drums	23 in. (584 mm)	16 in. (406 mm)	34 in. (864 mm)

TABLE 12-1 Packaging Size Specification for Commonly Used FCA Filler Wire

Spools Spools are made of plastic or fiberboard and are disposable. They are completely self-contained and are available in approximate weights from 1 lb up to approximately 50 lb (0.5 kg to 25 kg). The smaller spools, 4 in. and 8 in. (102 mm and 203 mm), weighing from 1 lb to 7 lb, are most often used for smaller production runs or for home/hobby use; 12-in. and 14-in. (305-mm and 356-mm) spools are often used in schools and welding fabrication shops.

Coils **Coils** come wrapped and/or wire-tied together. They are unmounted, so they must be supported on a frame on the wire feeder to be used. Coils are available in weights of approximately 60 lb (27 kg).

Reels Reels are large wooden **spools**, and drums are shaped like barrels. Both reels and drums are used for high-production jobs. Both can contain approximately 300 lb to 1000 lb (136 kg to 454 kg) of FCAW wire. Because of their size, they are used primarily at fixed welding stations. Such stations are often associated with some form of automation, such as turntables or robotics.

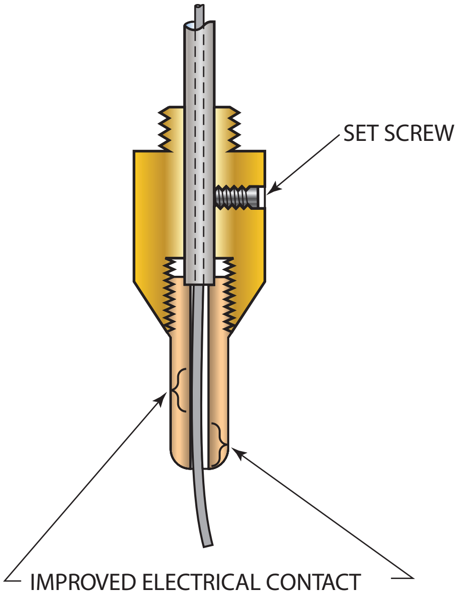


FIGURE 12-11 Cast forces the wire to make better electrical contact with the tube.

Electrode Cast and Helix

To see the cast and helix of a wire, feed out 10 ft (3 m) of wire electrode and cut it off. Lay it on the floor and observe that it forms a circle. The diameter of the circle is known as the cast of the wire, **Figure 12-10.**

Note that the wire electrode does not lay flat. One end is slightly higher than the other. This height is the helix of the wire.

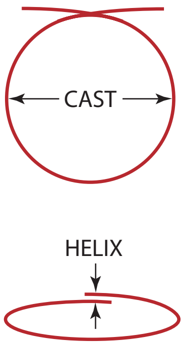


FIGURE 12-10 Method of measuring cast and helix of FCAW filler wire.

The AWS has specifications for both cast and helix for all FCA welding wires. The cast and helix cause the wire to rub on the inside of the contact tube, **Figure 12-11**. The slight bend in the electrode wire ensures a positive electrical contact between the contact tube and filler wire.

FCA WELDING ELECTRODE FLUX

The fluxes used are mainly rutile or lime-based. The purpose of the fluxes is the same as in the SMAW process. That is, they can provide all or part of the following to the weld:

- *Deoxidizers*: Oxygen that is present in the welding zone has two forms. It can exist as free oxygen from the atmosphere surrounding the weld. Oxygen also can exist as part of a compound such as an iron oxide or carbon dioxide (CO_2). In either case, it can cause porosity in the weld if it is not removed or controlled. Chemicals are added that react to the presence of oxygen in either form and combine to form a harmless compound, **Table 12-2**. The new compound can become part of the slag that solidifies on top of the

Deoxidizing Element	Strength
Aluminum (Al)	Very strong
Manganese (Mn)	Weak
Silicon (Si)	Weak
Titanium (Ti)	Very strong
Zirconium (Zr)	Very strong

TABLE 12-2 Deoxidizing Elements Added to Filler Wire (to Minimize Porosity in the Molten Weld Pool)

weld, or some of it may stay in the weld as very small inclusions. Both methods result in a weld with better mechanical properties with less porosity.

- *Slag formers:* Slag serves several vital functions for the weld. It can react with the molten weld metal chemically, and it can affect the weld bead physically. In the molten state it moves through the molten weld pool and acts as a magnet or sponge to chemically combine with impurities in the metal and remove them, **Figure 12-12**. Slags can be refractory, become solid at a high temperature, and solidify over the weld, helping it hold its shape and slowing its cooling rate.

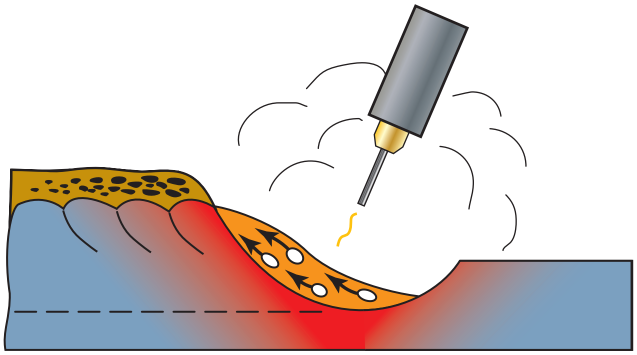


FIGURE 12-12 Impurities being floated to the surface by slag.

- *Fluxing agents:* Molten weld metal tends to have a high surface tension, which prevents it from flowing outward toward the edges of the weld. This causes undercutting along the junction of the weld and the base metal. Fluxing agents make the weld more fluid and allow it to flow outward, filling the undercut.
- *Arc stabilizers:* Chemicals in the flux affect the arc resistance. As the resistance is lowered, the arc voltage drops and penetration is reduced. When the arc resistance is increased, the arc voltage increases and weld penetration is increased. Although the resistance within the ionized arc stream may change, the arc is more stable and easier to control. It also improves the metal transfer by reducing spatter caused by an erratic arc.
- *Alloying elements:* Because of the difference in the mechanical properties of metal that is formed by rolling or forging and metal that is melted to form a weld bead, the metallurgical requirements of the two also differ. Some elements change the weld's strength, ductility, hardness, brittleness, toughness, and corrosion resistance. Powdered metal can be added to the flux and used as alloying elements or they may simply increase the deposition.
- *Shielding gas:* As elements in the flux are heated by the arc, some of them vaporize and form voluminous gaseous clouds hundreds of times larger than their original volume. This rapidly expanding cloud forces the air around the weld zone away from the molten weld metal, **Figure 12-13**. Without the protection this process affords the molten metal, it would rapidly oxidize. Such oxidization would severely affect the weld's mechanical properties, rendering it unfit for service.

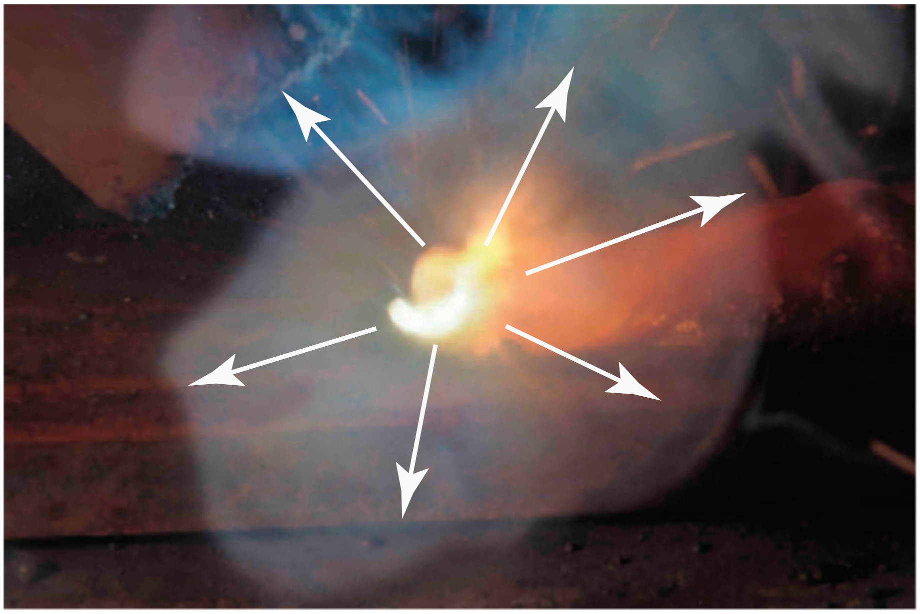


FIGURE 12-13 Rapidly expanding gas cloud.

TYPES OF FCAW FLUXES

All FCAW fluxes are divided into two groups based on the acid or basic chemical reactivity of the slag. The AWS classifies T-1 as acid and T-5 as basic.

Rutile Fluxes T-1 fluxes are **rutile-based fluxes** and they are acidic. They produce a smooth, stable arc and a refractory high-temperature slag for out-of-position welding. These refractory fluxes are sometimes called "***fast-freeze***" because they solidify at a higher temperature than the weld metal. By becoming solid first, this slag can cradle the molten weld pool and control its shape. This property is very important for out-of-position welds. The electrodes produce a fine drop transfer, a relatively low fume, and an easily removed slag. The main limitation of the rutile fluxes is that their fluxing elements do not produce a deposit with as high quality as the T-5 systems.

Lime Fluxes T-5 fluxes are **lime-based fluxes** and they are basic. They are very good at removing certain impurities from the weld metal, but their low melting temperature slag is fluid, which makes them generally unsuitable for out-of-position welding. These electrodes produce a more globular transfer, more spatter, more fume, and a more adherent slag than do the T-1 systems. These characteristics are tolerated when it is necessary to deposit very tough weld metal and for welding materials with a low tolerance for hydrogen.

Some rutile-based electrodes allow the addition of a shielding gas. With the weld being protected partially by the shielding gas, more elements can be added to the flux, which produces welds with the best of both flux systems, high-quality welds in all positions.

Some fluxes can be used on both single and multiple pass welds, and others are limited to single pass welds only. Using a single pass welding electrode for multipass welds may result in an excessive amount of manganese. The manganese is necessary to retain strength when making large, single pass welds. However, with the lower dilution associated with multipass techniques, it can strengthen the weld metal too much and reduce its ductility. In some cases, small welds that deeply penetrate the base metal can help control this problem.

Table 12-3 lists the shielding and polarity for the flux classifications of mild steel FCAW electrodes. The letter *G* is used to indicate an unspecified classification. The *G* means that the electrode has not been classified by the American Welding Society. Often the exact composition of fluxes is kept as a manufacturer's trade secret. Therefore, only limited information about the electrode's composition will be given. The only information often supplied is current, type of shielding required, and some strength characteristics.

As a result of the relatively rapid cooling of the weld metal, the weld may tend to become hard and brittle. This factor can be controlled by adding elements to the flux and the slag formed by the flux, **Table 12-4**. Ferrite is the softer, more ductile form of iron. The addition of ferrite-forming elements can control the hardness and brittleness of a weld.

Classifications		Comments		Shielding Gas
T-1		Requires clean surfaces and produces little spatter. It can be used for single and multiple pass welds in the flat (1G and 1F) and horizontal (2F) positions.		Carbon dioxide (CO_2)
T-2		Requires clean surfaces and produces little spatter. It can be used for single pass welds in the flat (1G and 1F) and horizontal (2F) positions only.		Carbon Dioxide (CO_2)
T-3		Used on thin-gauge steel for single pass welds in the flat (1G and 1F) and horizontal (2F) positions only.		None
T-4		Low penetration and moderate tendency to crack for single and multiple pass welds in the flat (1G and 1F) and horizontal (2F) positions.		None
T-5		Low penetration and a thin, easily removed slag, used for single and multiple pass welds in the flat (1G and 1F) positions only.		With or without carbon dioxide (CO_2)
T-6		Similar to T-5 without externally applied shielding gas.		None
T-G		The composition and classification of this electrode are not given in the preceding classes. It may be used for single or multiple pass welds.		With or without shielding

TABLE 12-3 Welding Characteristics of Seven Flux Classifications

Element	Reaction in Weld
Silicon (Si)	Ferrite former and deoxidizer
Chromium (Cr)	Ferrite and carbide former
Molybdenum (Mo)	Ferrite and carbide former
Columbium (Cb)	Strong ferrite former
Aluminum (Al)	Ferrite former and deoxidizer

TABLE 12-4 Ferrite-Forming Elements Used in FCA Welding Fluxes

The impurities in the weld pool can be metallic or nonmetallic compounds. Metallic elements that are added to the metal during the manufacturing process in small quantities may be concentrated in the weld. These elements improve the grain structure, strength, hardness, resistance to corrosion, or other mechanical properties in the metal's as-rolled or formed state. But weld nugget is a small casting, and some alloys adversely affect the properties of this casting (weld metal). Nonmetallic compounds are primarily slag inclusions left in the metal from the fluxes used during manufacturing. The welding fluxes form slags that are less dense than the weld metal so that they will float to the surface before the weld solidifies.

Flux Cored Steel Electrode Identification

The American Welding Society revised its A5.20 *Specification for Carbon Steel Electrodes for Flux Cored Arc Welding* in 1995 to reflect changes in the composition of the FCA filler metals. **Table 12-5** lists the AWS specifications for flux cored filler metals.

Mild Steel

The following electrode number is used as an example to explain the meaning for the specification of the electrode classification system *E70T-10* as follows **(Figure 12-14)**:

E—Electrode.

7— Tensile strength in units of 10,000 psi for a good weld. This value is usually either *6* for 60,000 psi or *7* for 70,000 psi minimum weld strength. An exception is for the number *12*, which is used to denote filler metals with a range from 70,000 psi to 90,000 psi.

0—*0* is used for flat and horizontal fillets only, and *1* is used for all-position electrodes.

T—Tubular (flux cored) electrode.

Metal	AWS Filler Metal Classification
Mild steel	A5.20
Stainless steel	A5.22
Chromium-molybdenum	A5.29

TABLE 12-5 Filler Metal Classification Numbers

10—The number in this position can range from *1* to *14* and is used to indicate the electrode's shielding gas, if any, number of passes, and other welding characteristics of the electrode. The letter *G* is used to indicate that the shielding gas, polarity, and impact properties are not specified. The letter *G* may or may not be followed with the letter *S*. The S is only used for single pass welding.

The electrode classification *E70T-10* can have some optional identifiers added to the end of the number such as *E70T-10MJH8*. These additions are used to add qualifiers to the general classification so that specific codes or standards can be met. These additions have the following meanings:

M—Mixed gas, 75% to 80% Ar, balance CO_2. If there is no *M*, then the shielding gas must be either CO_2 or the electrode is self-shielded.

J—Describes the Charpy V-notch impact test value of 20 ft-lb at −40°F.

H8—Describes the residual hydrogen levels in the weld: *H4* equals less than 4 ml/l00 g; *H8* equals less than 8 ml/100 g; *H16* equals less than 16 ml/l00 g.

Stainless Steel Electrodes

The AWS classification for stainless steel for FCAW electrodes starts with the letter *E* as its prefix. Following the *E* prefix, the American Iron and Steel Institute's (AISI) three-digit stainless steel number is used. This number indicates the type of stainless steel in the filler metal.

To the right of the AISI number, the AWS adds a dash followed by a suffix number. The number 1 is used to indicate an all-position filler metal, and the number 3 is used to indicate an electrode to be used in the flat and horizontal positions only.

Metal Cored Steel Electrode Identification

The addition of metal powders to the flux core of FCA welding electrodes has produced a new classification of filler metals. The new filler metals evolved over time, and a new identification system was established by the AWS to identify these filler metals. Some of the earlier flux cored filler metals that already had powder metals in their core had their numbers changed to reflect the new designation. The designation was changed from the letter *T* for ***tubular*** to the letter *C* for *core.* For example, E70T-1 became E70C-3C. The complete explanation of the cored electrode *E70C-3C* follows:

E—Electrode.

7—Tensile strength in units of 10,000 psi for a good weld. This value is usually either *6* for 60,000 psi or *7* for 70,000 psi minimum weld strength. An exception is for the number *12*, which is used to denote filler metals with a range from 70,000 psi to 90,000 psi.

Mandatory Classification Designators[a]

Designates an electrode.

Tensile Strength Designator. For A5.36 one or two digits indicate the minimum tensile strength (when multiplied by 10,000 psi) of weld metal deposited with the electrode under the welding conditions specified in this specification. For A5.36M two digits are used to indicate the minimum tensile strength (when multiplied by 10 Megapascals [MPa]). See Table 2.

Position Designator. This designator is either "0" or "1." A "0" is for flat and horizontal positions only. "1" is for all positions (flat, horizontal, vertical with downward progression, and/or vertical with upward progression and overhead).

Usability Designator. This letter is the letter "T" followed by some number from 1 through 17 or the letter "G." The letter "T" identifies the electrode as a flux cored electrode or metal cored electrode. This designator refers to the usability of the electrode with requirements for polarity and general operating characteristics (see Table 4). The letter "G" indicates that the polarity and general operating characteristics are not specified. An "S" appears at the end of this designator when the electrode being classified is intended for single pass welding only.

Shielding Gas Designator. Indicates the type of shielding gas, if any, used for classification (see Table 5). The letter "Z" in this position indicates that the shielding gas composition is as agreed upon between supplier and purchaser. When no designator appears in this position, it indicates that the electrode is self shielded and that no external shielding gas is used.

Designates the condition of heat treatment in which the tests were conducted. "A" is for as-welded and "P" is for postweld heat treated. The time and temperature of the PWHT is specified in 9.2.1.2 and Table 8. The letter "G" in this position indicates that the PWHT procedure is as agreed upon between supplier and purchaser. This designator omitted when the electrode being classified is intended for single pass welding only.

Impact Designator. For A5.36 this designator indicates the temperature in °F at or above which the impact strength of the weld metal referred to above meets or exceeds 20 ft·lbf. For A5.36M this designator indicates the temperature in °C at or above which the impact strength of the weld metal meets or exceeds 27 J. The impact designator may be either one or two digits (see Table 3). A "Z" in this position indicates that there are no impact requirements for the electrode classification. This designator is omitted when the electrode being classified is intended for single pass welding only. A "G" in this position indicates the impact requirements are not specified but are as agreed upon between purchaser and supplier.

Deposit Composition Designator. One, two, or three characters are used to designate the composition of the deposited weld metal (see Table 6). The letter "G" indicates that the chemical composition is not specified. No designator used in this position when the electrode being classified is a single pass electrode.

E X X T X - X X X - X - X H X **Optional Supplemental Designators**[b]

Optional, supplemental diffusible hydrogen designator (see Table 13).

For flux cored electrodes, the letter "D" or "Q" when present in this position indicates the weld metal will meet supplemental mechanical property requirements with welding done using low heat input, fast cooling rate procedures and using high heat input, slow cooling rate procedures as prescribed in Clause 16 (see Tables 9 and 10).

[a] The combination of these designators constitutes the flux cored electrode classification.
[b] These designators are optional and do not constitute a part of the flux cored or metal cored electrode classification, as applicable.

FIGURE 12-14 Identification system for mild steel FCAW electrodes.

0—*0* is used for flat and horizontal fillets only, and *1* is used for all-position electrodes.

C—Metal-cored (tubular) electrode.

3—*3* is used for a Charpy impact of 20 ft-lb at 0°F, and *6* represents a Charpy impact of 20 ft-lb at −20°F.

C—The second letter *C* indicates CO_2

M—Indicates a mixed gas, 75% to 80% Ar, with the balance being CO_2. If there is no *M* or *C*, then the shielding gas is CO_2.

G—Used to indicate that the shielding gas, polarity, and impact properties are not specified.

S—The letter S may follow the letter G to indicate an electrode suitable only for single pass welding.

NOTE

The powdered metal added to the core flux can provide additional filler metal and/or alloys. This is one way the microalloys can be added in very small and controlled amounts, as low as 0.0005% to 0.005%. These are very powerful alloys that dramatically improve the metal's mechanical properties.

Care of Flux Core Electrodes

Wire electrodes may be wrapped in sealed plastic bags for protection from the elements. Others may be wrapped in a special paper, and some are shipped in cans or cardboard boxes.

A small paper bag of a moisture-absorbing material, crystal desiccant, is sometimes placed in the shipping containers. It is enclosed to protect wire electrodes from moisture. Some wire electrodes require storage in an electric rod oven to prevent contamination from excessive moisture. Read the manufacturer's recommendations located in or on the electrode shipping container for information on use and storage.

Weather conditions affect your ability to make high-quality welds. Humidity increases the chance of moisture entering the weld zone. Water (H_2O), which consists of two parts hydrogen and one part oxygen, separates in the weld pool. When only one part of hydrogen is expelled, hydrogen entrapment occurs. Hydrogen entrapment can cause weld beads to crack or become brittle. The evaporating moisture will also cause porosity.

To prevent hydrogen entrapment and porosity, storing the wire electrode in a dry location is recommended. The electrode may develop restrictions due to the tangling of the wire or become oxidized with excessive rusting if the wire electrode package is mishandled, thrown, dropped, or stored in a damp location.

CAUTION

Always keep the wire electrode dry and handle it as you would any important tool or piece of equipment.

SHIELDING GAS

FCA welding wire can be manufactured so that all of the required shielding of the molten weld pool is provided by the vaporization of some of the flux within the tubular electrode. When the electrode provides all of the shielding, it is called **self-shielding**. Other FCA welding wire must use an externally supplied shielding gas to provide the needed protection of the molten weld pool. When a shielding gas is added, it is called **dual shield**.

NOTE

Sometimes the shielding gas is referred to as the shielding medium. For example, the shielding gas for E71T-5 is either argon 75% with 25% CO_2 or 100% CO_2.

Care must be taken to use the cored electrodes with the recommended gases or to not use gas at all with the self-shielded electrodes. Using a self-shielding flux cored electrode with a shielding gas may produce a defective weld. The shielding gas will prevent the proper disintegration of much of the deoxidizers. This results in the transfer of these materials across the arc to the weld. In high concentrations, the deoxidizers can produce slags that become trapped in the welds, causing undesirable defects. Lower concentrations may cause brittleness only. In either case, the chance of weld failure is increased. If these electrodes are used correctly, then there is no problem.

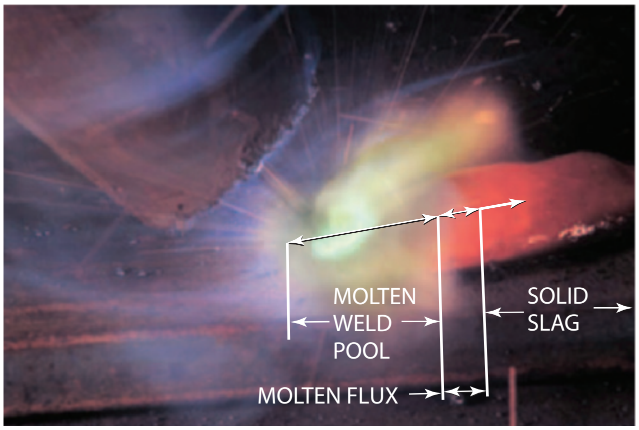
The selection of a shielding gas will affect the arc and weld properties. The weld bead width, buildup, penetration, spatter, chemical composition, and mechanical properties are all affected as a result of the shielding gas selection.

Cylinder Safety Shielding gas comes in high-pressure cylinders. These cylinders are supplied with 2000 psi of pressure. Because of this high pressure, it is important for these cylinders to be handled and stored safely. See Chapter 2 for specific cylinder safety instructions.

Argon and CO_2 Gases used for FCA welding include CO_2 and mixtures of argon and CO_2. Argon gas is easily ionized by the arc. Ionization results in a highly concentrated path from the electrode to the weld. This concentration results in a smaller droplet size that is associated with the axial spray mode of metal transfer, **Figure 12-15**. A smooth, stable arc results and there is a minimum of spatter. This transfer mode continues as CO_2 is added to the argon until the mixture contains more than 25% of CO_2.

As the percentage of CO_2 increases in the argon mixture, weld penetration increases. This increase in penetration continues until a 100% CO_2 shielding gas is reached. But as the percentage of CO_2 is increased, the arc stability decreases. The less stable arc causes an increase in spatter. A mixture of 75% argon and 25% CO_2 works best for jobs requiring a mixed gas. This mixture is sometimes called C-25.

100% CO_2 Straight CO_2 is used for some welding. But the CO_2 gas molecule is easily broken down in the welding arc. It forms carbon monoxide (CO) and free oxygen (O).



Larry Jeffus

FIGURE 12-15 Axial spray transfer mode.

Both gases are reactive to some alloys in the electrode. As these alloys travel from the electrode to the molten weld pool, some of them form oxides. Silicon and manganese are the primary alloys that become oxidized and lost from the weld metal.

Most FCA welding electrodes are specifically designed to be used with or without shielding gas and for a specific shielding gas or percentage mixture. For example, an electrode designed specifically for use with 100% CO_2 will have higher levels of silicon and manganese to compensate for the losses to oxidization. But if 100% argon or a mixture of argon and CO_2 is used, then the weld will have an excessive amount of silicon and manganese. The weld will not have the desired mechanical or metallurgical properties. Although the weld may look satisfactory, it will probably fail prematurely.

CAUTION

Never use an FCA welding electrode with a shielding gas it is not designated to be used with. The weld it produces may be unsafe.

WELDING TECHNIQUES

A welder can control weld beads made by FCA welding by making changes in the techniques used. The following explains how changing specific welding techniques will affect the weld produced.

Gun Angle

The *gun angle* and *travel angle* are terms used to refer to the relation of the gun to the work surface, **Figure 12-16**. The gun angle can be used to control the weld pool. The electric arc produces an electrical force known as the arc force. The arc force can be used to counteract the gravitational pull that tends to make the liquid weld pool sag or run ahead of the arc. By manipulating the electrode travel angle for the flat and horizontal position of welding to a 20° to 45° angle from the vertical, the weld pool can be controlled. A 40° to 50° angle from the vertical plate is recommended for fillet welds.

Changes in this angle will affect the weld bead shape and penetration. Shallower angles are needed when welding thinner materials to prevent burnthrough. Steeper, perpendicular angles are used for thicker materials.

FCAW electrodes have a flux that is mineral-based, often called low hydrogen. These fluxes are refractory and become solid at a high temperature. If too steep of a forehand or pushing angle is used, then slag from the electrode can be pushed ahead of the weld bead and solidify quickly on the cooler plate, **Figure 12-17**. Because the slag remains solid at higher temperatures than the temperature of the molten weld pool, it can be trapped under the edges of the weld by the molten weld metal. To avoid this problem, most flat and horizontal welds should be performed with a backhand angle.

Vertical up welds require a **forehand** gun angle. The forehand angle is needed to direct the arc deep into the groove or joint for better control of the weld pool and

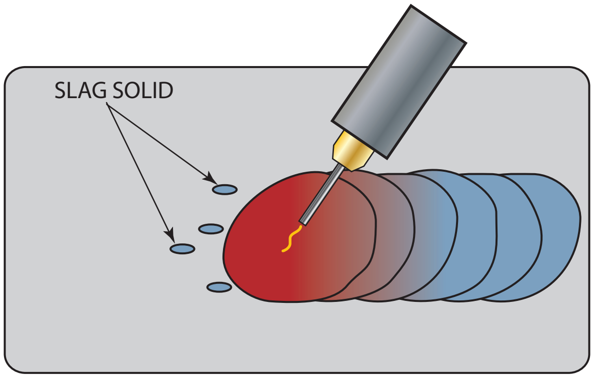


FIGURE 12-17 Large quantities of solid slag in front of a weld can cause slag to be trapped under the weld bead.

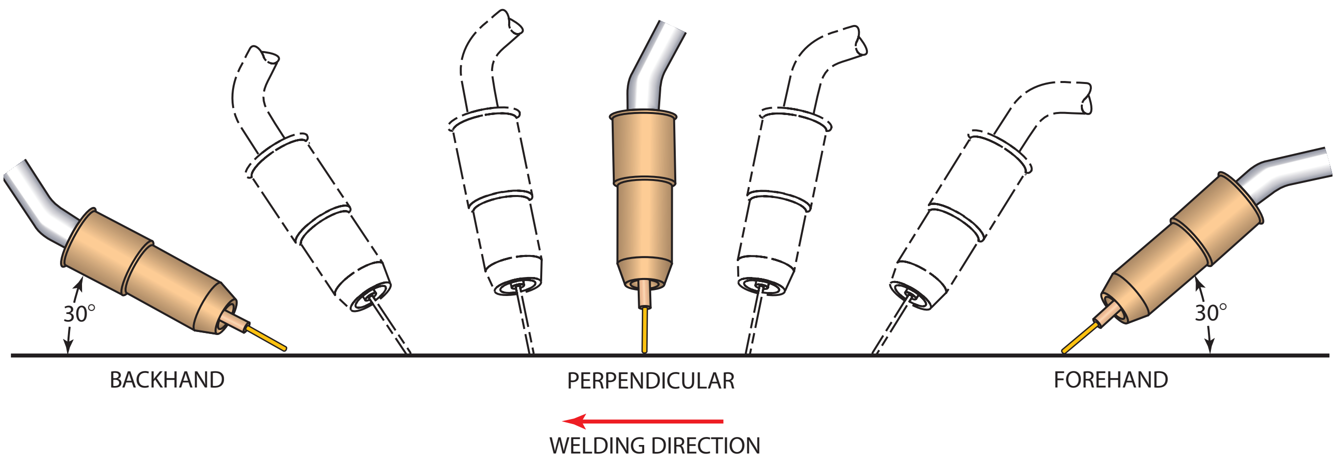


FIGURE 12-16 Welding gun angles.

deeper penetration, **Figure 12-18**. Slag entrapment associated with most forehand welding is not a problem for vertical welds.

A gun angle approximately 90° to the metal surface either slightly forehand or backhand works best for overhead welds, **Figure 12-19**. The slight angle aids with visibility of the weld, and it helps control spatter buildup in the gas nozzle.

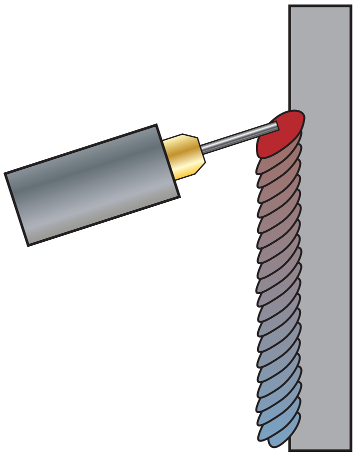


FIGURE 12-18 Vertical up gun angle.

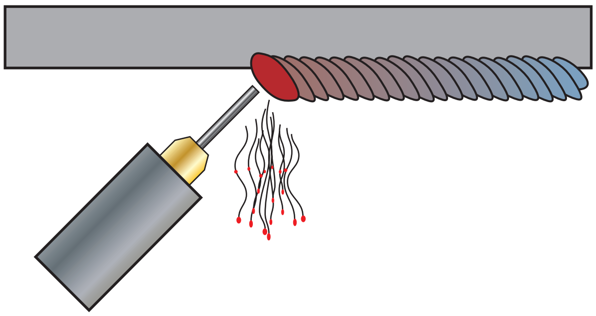


FIGURE 12-19 Weld gun position to control spatter buildup on an overhead weld.

FOREHAND/PERPENDICULAR/ BACKHAND TECHNIQUES

Forehand, *perpendicular*, and *backhand* are the terms most often used to describe the gun angle as it relates to the work and the direction of travel. The forehand technique is sometimes referred to as *pushing* the weld bead, and backhand may be referred to as *pulling* or *dragging* the weld bead. The term *perpendicular* is used when the gun angle is at approximately 90° to the work surface, **Figure 12-20**.

Advantages of the Forehand Technique

The advantages of using the forehand welding technique are as follows:

- Joint visibility—You can easily see the joint where the bead will be deposited, **Figure 12-21.**
- Electrode extension—The contact tube tip is easier to see, making it easier to maintain a constant extension length.
- Less weld penetration—It is easier to weld on thin sheet metal without melting through.

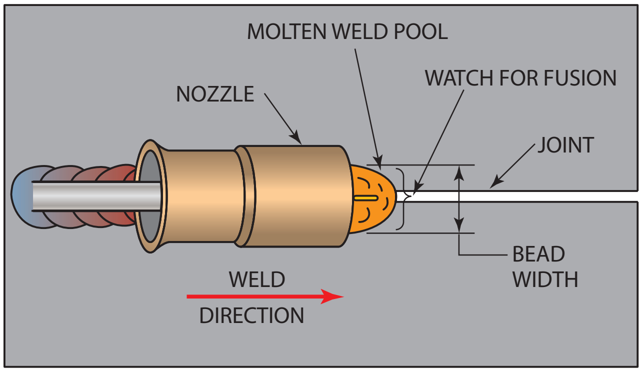


FIGURE 12-21 The shielding gas nozzle restricts the welder's view.

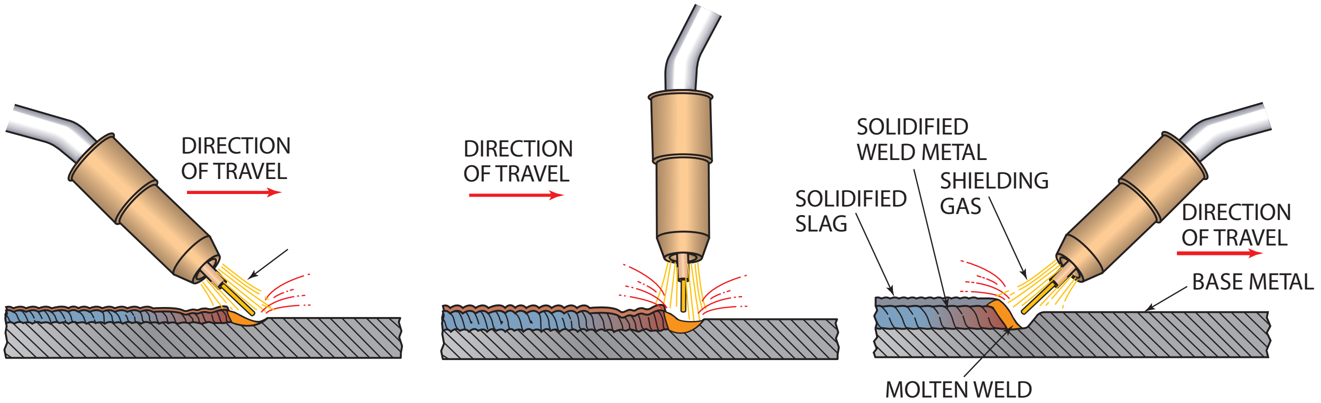


FIGURE 12-20 Changing the welding gun angle between forehand, perpendicular, or backhand angles will change the shape of the weld bead produced.

- Out-of-position welds—This technique works well on vertical up and overhead joints for better control of the weld pool.

Disadvantages of the Forehand Technique

The disadvantages of using the forehand welding technique are as follows:

- Weld thickness—Thinner welds result because less weld reinforcement is applied to the weld joint.
- Welding speed—Because less weld metal is being applied, the rate of travel along the joint can be faster, which may make it harder to create a uniform weld.
- Slag inclusions—Some spattered slag can be thrown in front of the weld bead and be trapped or included in the weld, resulting in a weld defect.
- Spatter—Depending on the electrode, the amount of spatter may be slightly increased with the forehand technique.

Advantages of the Perpendicular Technique

The advantages of using the perpendicular welding technique are as follows:

- Machine and robotic welding—The perpendicular gun angle is used on automated welding because there is no need to change the gun angle when the weld changes direction.
- Uniform bead shape—The weld's penetration and reinforcement are balanced between those of forehand and backhand techniques.

Disadvantages of the Perpendicular Technique

The disadvantages of using the perpendicular welding technique are as follows:

- Limited visibility—Because the welding gun is directly over the weld, there is limited visibility of the weld unless you lean your head way over to the side.
- Weld spatter—Because the weld nozzle is directly under the weld in the overhead position, more weld spatter can collect in the nozzle causing gas flow problems or even shorting the tip to the nozzle.

Advantages of the Backhand Technique

The advantages of the backhand welding technique are as follows:

- Weld bead visibility—It is easy to see the back of the molten weld pool as you are welding, which makes it easier to control the bead shape.
- Travel speed—Because of the larger amount of weld metal being applied, the rate of travel may be slower, making it easier to create a uniform weld.
- Depth of fusion—The arc force and the greater heat from the slower travel rate both increase the depth of weld joint penetration.

Disadvantages of the Backhand Technique

The disadvantages of the backhand welding technique are as follows:

- Weld buildup—The weld bead may have a convex (raised or rounded) shaped weld face when you use the backhand technique.
- Postweld finishing—Because of the weld bead shape, more work may be required if the product has to be finished by grinding smooth.
- Joint following—It is harder to follow the joint because of your hand position with the FCAW gun being positioned over the joint, and you may wander from the seam, **Figure 12-22**.
- Loss of penetration—An inexperienced welder sometimes directs the wire too far back into the weld pool, causing the wire to build up in the face of the weld pool, reducing joint penetration.

Travel Speed

The American Welding Society defines *travel speed* as the linear rate at which the arc is moved along the weld joint. Fast travel speeds deposit less filler metal. If the rate of travel increases, then the filler metal cannot be deposited fast enough to adequately fill the path melted by the arc. This causes the weld bead to have a groove melted into the base metal next to the weld and left unfilled by the weld. This condition is known as undercut.

Undercut occurs along the edges or toes of the weld bead. Slower travel speeds will, at first, increase penetration and increase the filler weld metal deposited. As the

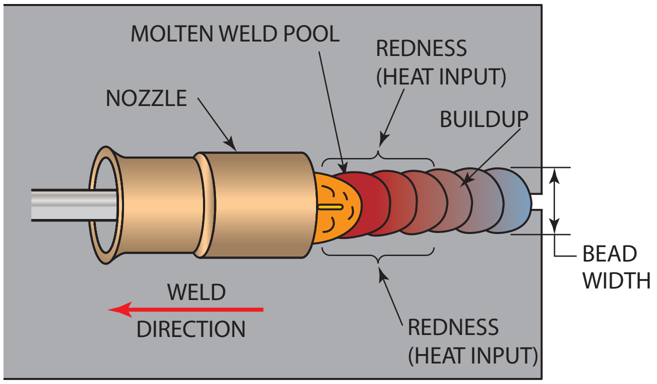


FIGURE 12-22 Watch the trailing edge of the molten weld pool.

filler metal increases, the weld bead will build up in the weld pool. Because of the deep penetration of flux cored wire, the angle at which you hold the gun is very important for a successful weld.

If all welding conditions are correct and remain constant, the preferred rate of travel for maximum weld penetration is a travel speed that allows you to stay within the selected welding variables and still control the fluidity of the weld pool. This is an intermediate travel speed, or progression, that is not too fast or too slow.

Another way to figure out correct travel speed is to consult the manufacturer's recommendations chart for the ipm burn-off rate for the selected electrode.

MODE OF METAL TRANSFER

The mode of metal transfer is used to describe how the molten weld metal is transferred across the arc to the base metal. The mode of metal transfer that is selected, the shape of the completed weld bead, and the depth of weld penetration depend on the welding power source, wire electrode size, type and thickness of material, type of shielding gas used, and best welding position for the task.

Spray Transfer—FCAW-G

The spray transfer mode is the most common process used with gas shielded FCAW, **Figure 12-23**.

As the gun trigger is depressed, the shielding gas automatically flows and the electrode bridges the distance from the contact tube to the base metal, making contact with the base metal to complete a circuit. The electrode shorts and becomes so hot that the base metal melts and forms a weld pool. The electrode melts into the weld pool and burns back toward the contact tube. A combination of high amperage and the shielding gas along with the electrode size produces a pinching effect on the molten electrode wire, causing the end of the electrode wire to spray across the arc.

The characteristic of spray-type transfer is a smooth arc, through which hundreds of small droplets per second are transferred through the arc from the electrode to the weld pool. At that moment, a transfer of metal is taking place. Spray transfer can produce a high quantity of metal droplets, up to approximately 250 per second above the transition current, or critical current. This means the current is dependent on the electrode size, composition of the electrode, and shielding gas so a spray transfer can take place. Below the transition current (critical current), globular transfer takes place.

To achieve a spray transfer, high current and larger diameter electrode wire are needed. A shielding gas of carbon dioxide (CO_2), a mixture of carbon dioxide (CO_2) and argon (Ar), or an argon (Ar) oxygen (O_2) mixture is needed. FCAW-G is a welding process that, with the correct variables, can be used

- on thin or properly prepared thick sections of material,
- on a combination of thick to thin materials,
- with small or large electrode diameters, and
- with a combination of shielding gases.

Globular Transfer—FCAW-G

Globular transfer occurs when the welding current is below the transition current, **Figure 12-24**. The electrode forms a molten ball at its end that grows in size to approximately two-times to three-times the original electrode diameter. These large molten balls are then transferred across the arc at the rate of several drops per second.

The arc becomes unstable because of the gravitational pull from the weight of these large drops. A spinning effect caused by a natural phenomenon takes place when argon gas is introduced to a large ball of molten metal on the electrode. This causes a spinning motion as the molten ball transfers across the arc to the base metal. This unstable globular transfer can produce excessive spatter.

Both FCAW-S and FCAW-G use DCEP. Some FCAW-S can use DCEN. The recommended weld position means the position in which the workpiece is placed for welding. All welding positions use either spray or globular transfer,

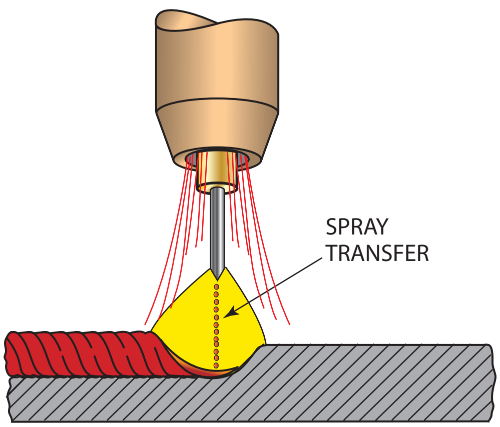


FIGURE 12-23 Spray transfer method.

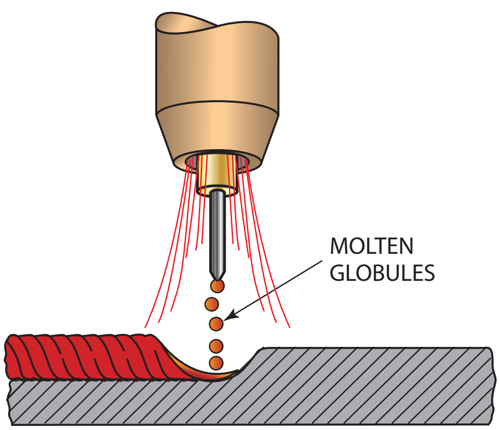


FIGURE 12-24 Globular transfer method.

but for now we concentrate on the flat and horizontal welding positions.

In the flat welding position, the workpiece is placed flat on the work surface. In the horizontal welding position, the workpiece is positioned perpendicular to the workbench surface.

The amperage range may be from 30 amperes to 400 amperes or more for welding materials from gauge thickness up to 1 1/2 in. (37 mm). On square-groove weld joints, thicker base metals can be welded with little or no edge preparation. This is one of the great advantages of FCAW. If edges are prepared and cut at an angle (beveled) to accept a complete joint weld penetration, then the depth of penetration will be greatly increased. FCAW is commonly used for general repairs to mild steel in the horizontal, vertical, and overhead welding positions, sometimes referred to as out-of-position welding.

Electrode Extension

The electrode extension is measured from the end of the electrode contact tube to the point the arc begins at the end of the electrode, **Figure 12-25**. Compared to GMA welding, the electrode extension required for FCAW is much greater. The longer extension is required for several reasons. The electrical resistance of the wire causes the wire to heat up, which can drive out moisture from the flux. This preheating of the wire also results in a smoother arc with less spatter.

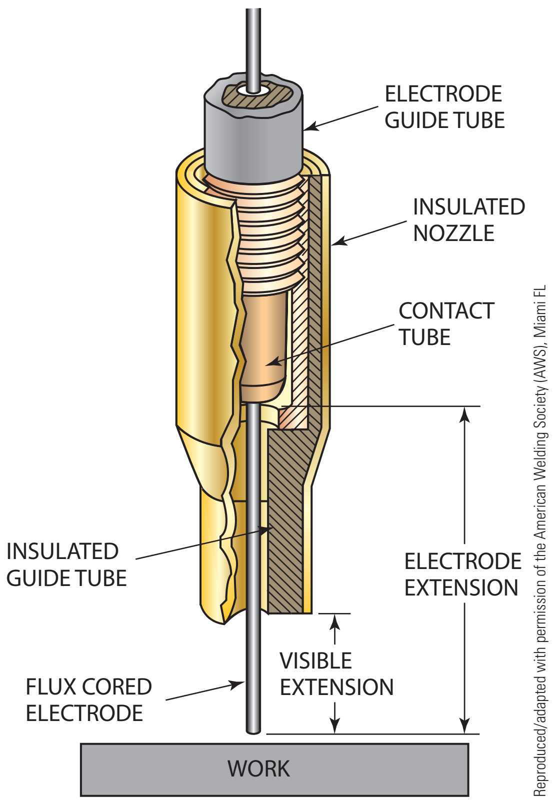


FIGURE 12-25 Self-shielded electrode nozzle.

Porosity

FCA welding can produce high-quality welds in all positions, although porosity in the weld can sometimes be a problem. Porosity can be caused by moisture in the flux, improper gun manipulation, or surface contamination.

The flux used in the FCA welding electrode is subject to picking up moisture from the surrounding atmosphere, so the electrodes must be stored in a dry area. Once the flux becomes contaminated with moisture, it is very difficult to remove. Water (H_2O) breaks down into free hydrogen and oxygen in the presence of an arc, **Figure 12-26**. The hydrogen can be absorbed into the molten weld metal, where it can cause postweld cracking. The oxygen is absorbed into the weld metal also, but it forms oxides in the metal.

If a shielding gas is being used, the FCA welding gun gas nozzle must be close enough to the weld to provide adequate shielding gas coverage. If there is a wind or if the nozzle-to-work distance is excessive, then the shielding will be inadequate and cause weld porosity. If welding is to be done outside or in an area subject to drafts, then the gas flow rate must be increased or a windshield must be placed to protect the weld, **Figure 12-27**.

A common misconception is that the flux within the electrode will either remove or control weld quality problems caused by surface contaminations. That is not true. The addition of flux makes FCA welding more tolerant to surface conditions than GMA welding, although it still is adversely affected by such contaminations.

New hot-rolled steel has a layer of dark gray or black iron oxide called ***mill scale***. Although this layer is very thin, it may provide a source of enough oxygen to cause porosity in the weld. If mill scale causes porosity, it is usually uniformly scattered through the weld, **Figure 12-28**. Unless severe, uniformly scattered porosity is usually not visible in the finished weld. It is trapped under the surface as the weld cools.

Because porosity is under the weld surface, nondestructive testing methods, including X-ray, magnetic particle, and ultrasound, can be used to locate it in a

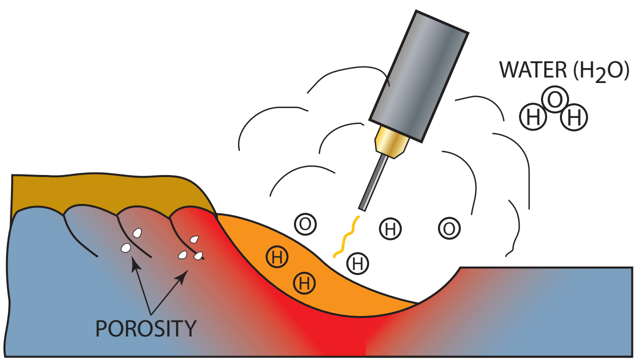


FIGURE 12-26 Water (H_2O) breaks down in the presence of the arc and the hydrogen (H) is dissolved in the molten weld metal.

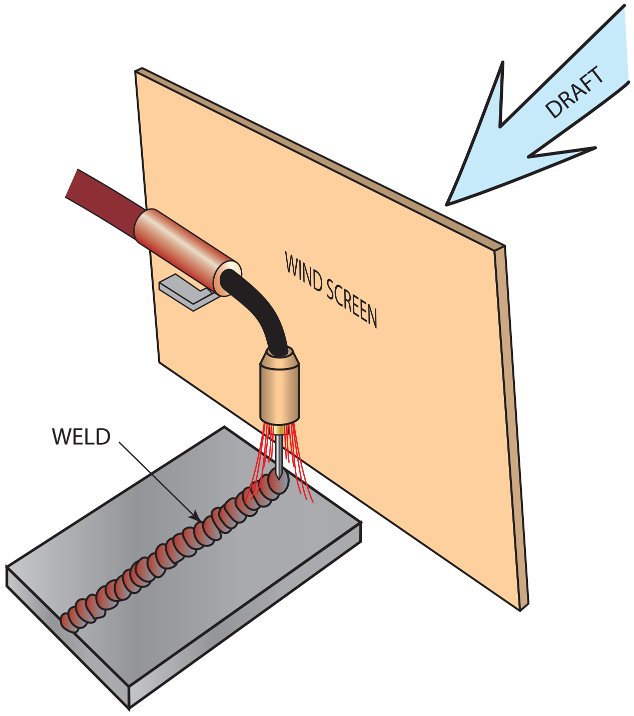


FIGURE 12-27 A windscreen can keep the welding shielding from being blown away.

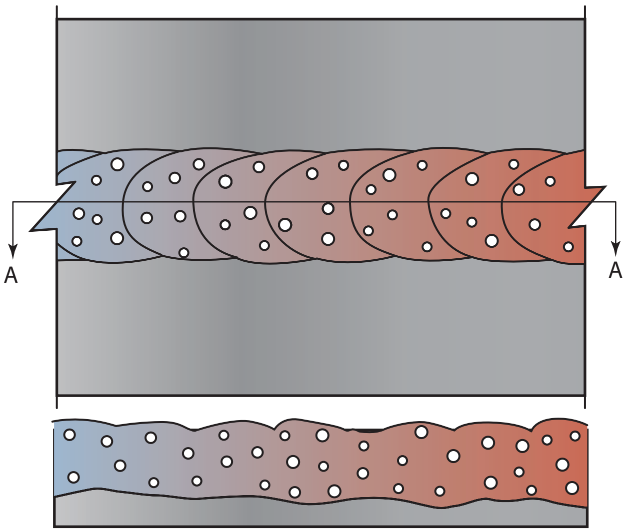


FIGURE 12-28 Uniformly scattered porosity.

weld. It can be detected by mechanical testing such as guided-bend, free-bend, and nick-break testing for establishing weld parameters. Often it is better to remove the mill scale before welding rather than risking the production of porosity.

All welding surfaces within the weld groove and the surrounding surfaces within 1 in. (25 mm) must be cleaned to bright metal, **Figure 12-29**. Cleaning may be grinding, filing, sanding, or blasting.

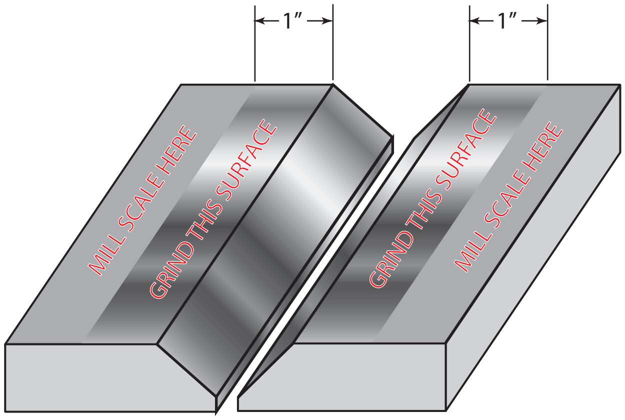


FIGURE 12-29 Grind mill scales off plates within 1 in. (25 mm) of the groove.

Any time FCA welds are to be made on metals that are dirty, oily, rusty, or wet or that have been painted, the surface must be precleaned. Cleaning can be done chemically or mechanically.

CAUTION

Chemically cleaning oil and paint off metal must be done according to the cleaner manufacturer's directions. The work must be done in an appropriate, approved area. The metal must be dry, and all residues of the cleaner must be removed before welding begins.

One advantage of chemically cleaning oil and paint is that it is easier to clean larger areas. Both oil and paint smoke easily when heated, and such smoke can cause weld defects. They must be removed far enough from the weld so that weld heat does not cause them to smoke. In the case of small parts, the entire part may need to be cleaned.

TROUBLESHOOTING FCA WELDING

Troubleshooting FCA welding problems is often a trial-and-error process. Trial and error is where you make one adjustment or change at a time and make a trial weld to see if the problem improved. If what you tried did not improve the problem or made it worse, then reset the machine and try another adjustment. Keep doing this until the problem is resolved. Make only one adjustment or change at a time. Making two or more adjustments or changes at the same time can result in one improving the weld and the others causing new problems.

The most common causes of FCA welding problems are equipment setup. However, in the field, worn and

Welding Problem	Cause
Gun nozzle arcs to work	1. Weld spatter buildup in nozzle 2. Contact tube bent and touching nozzle
Wire feeds but no arc	1. Bad or missing work clamp (ground) 2. Loose jumper lead in welder 3. Electrode not contacting bare metal
Arc burns off wire at contact tube end	1. Feed rollers tension too loose 2. Wrong sized feed rollers 3. Wire welded to contact tube 4. Wire liner worn or damaged 5. Out of wire 6. Worn or damaged contact tube
Wire feeds erratically	1. Feed rollers tension loose 2. Dirty liner 3. Worn or dirty contact tube
Arc pops and gun jerks during welding	1. Too high a wire feed speed 2. Too low a voltage
Wire burns back and large globules of metal cross the arc	1. Too high a voltage 2. Too low a wire feed speed 3. Wire slipping in feed rollers, not feeding smoothly
Weld does not burn into base metal	1. Too long an electrode extinction 2. Too low voltage and amperage settings
Weld burns through the base metal	1. Too short an electrode extinction 2. Too high voltage and amperage settings
Porosity in weld	1. Poor shielding gas coverage on dual-shield wire 2. Wrong shielding gas type being used 3. Shielding gas used on self-shielding wire 4. Single pass electrode used for multi pass weld
Poor shielding gas coverage	1. Plugged or dirty gas diffuser 2. Too high or too low shielding gas flow rate 3. Shielding gas cylinder near empty

TABLE 12-6 FCAW Troubleshooting Table

dirty parts will from time to time develop problems. These worn or dirty parts can cause FCA welding problems similar to those caused by improper setup. Misdiagnosing the cause can result in the possible replacement of good parts. To reduce this time and expense, use the list of common FCA welding problems in **Table 12-6** to try to solve the weld problem before replacing parts. Often the equipment manufacturer will include a list of troubleshooting tips in the welder manufacturer's instruction booklet.

Summary

Flux cored arc welding is used to produce more tons of welded fabrications than any other process. The ability to produce high-quality welds on a wide variety of material thicknesses and joint configurations has led to its popularity. As you learn and develop these skills, you will therefore be significantly increasing your employability and productivity in the welding industry.

A wide variety of flux cored arc welding filler metals and shielding gas combinations are available to you in industry. These various materials aid in producing welds of high quality under various welding conditions. Although the selection of the proper filler metal and gas coverage, if used, will significantly affect the finished weld's quality in the field, there are very few differences in manipulation and setup among these filler metals. Therefore, as you practice welding in a school or training program and learn to use a specific wire and shielding gas mixture, these skills are easily transferable to the next group of materials you will encounter on the job.

Review

1. List some factors that have led to the increased use of FCA welding.
2. How is FCAW similar to GMAW?
3. What does the FCA flux provide to the weld?
4. What are the major atmospheric contaminations of the molten weld metal?
5. How does slag help an FCA weld?
6. How can FCA welding guns be cooled?
7. Excessive drive roller pressure causes what problems?
8. List the advantages that FCA welding offers the welding industry.
9. Describe the two methods of manufacturing FCA electrode wire.
10. Why are the large diameter electrodes not used for all-position welding?
11. How do deoxidizers remove oxygen from the weld zone?
12. What do fluxing agents do for a weld?
13. Why are alloying elements added to the flux?
14. How does the flux form a shielding gas to protect the weld?
15. What are the main limitations of the rutile fluxes?
16. Why is it more difficult to use lime-based fluxed electrodes on out-of-position welds?
17. What benefit does adding an externally supplied shielding gas have on some rutile-based electrodes?
18. How do excessive amounts of manganese affect a weld?
19. Why are elements added that cause ferrite to form in the weld?
20. Why must a flux form a less dense slag?
21. Referring to Table 12-5, what is the AWS classification for FCA welding electrodes for stainless steel?
22. Describe the meaning of each part of the following FCA welding electrode identification: E81T-5.
23. What does the number 316 in E316T-1 mean?
24. What is the advantage of using an argon-CO_2 mixed shielding gas?
25. Why are some slags called refractory?
26. What can happen to slag that solidifies on the plate ahead of the weld?
27. How is the electrode extension measured?
28. What can cause porosity in an FCA weld?
29. What happens to water in the welding arc?
30. What is the thin dark gray or black layer on new hot-rolled steel? How can it affect the weld?
31. Why is uniformly scattered porosity hard to detect in a weld?
32. What cautions must be taken when chemically cleaning oil or paint from a piece of metal?

Chapter 13

Flux Cored Arc Welding

OBJECTIVES

After completing this chapter, the student should be able to

- explain the purpose of setting up the FCA weld station properly.
- demonstrate how to properly set up an FCA welding station and how to thread the electrode wire through the system.
- discuss the disadvantages of having to bevel a plate before welding.
- describe how to make root, filler, and cover passes in FCA welding.
- demonstrate how to properly make FCA welds in butt joints, lap joints, and tee joints in all positions that can pass the specified standard.

KEY TERMS

amperage range
conduit liner
contact tube
critical weld
feed rollers
lap joint
root face
stringer bead
tee joint
voltage range
weave bead
wire-feed speed

INTRODUCTION

Setup of the FCA weld station is the key to making quality welds. It may be possible to make an acceptable weld in the flat position using a poorly set-up FCA welder. The FCA welding process is often forgiving; thus, welds can often be made even when the welder is not set correctly. However, such welds will have major defects such as excessive lack of fusion, spatter, undercut, overlap, porosity, slag inclusions, and poor weld bead contours. Setup becomes even more important for out-of-position welds. Making vertical and overhead welds can be difficult for a student welder with a properly set up system, but it becomes impossible with a system that is out of adjustment.

Learning to set up and properly adjust the FCA welding system will allow you to produce high-quality welds at a high level of productivity.

FCAW is set up and manipulated in a manner similar to that of GMAW. The results of changes in electrode extension, voltage, amperage, and torch angle are essentially the same.

Although every manufacturer's FCA welding equipment is designed differently, all equipment is set up in a similar manner. It is always best to follow the specific manufacturer's recommendations regarding setup as provided in its equipment literature. However, you will find that, in the

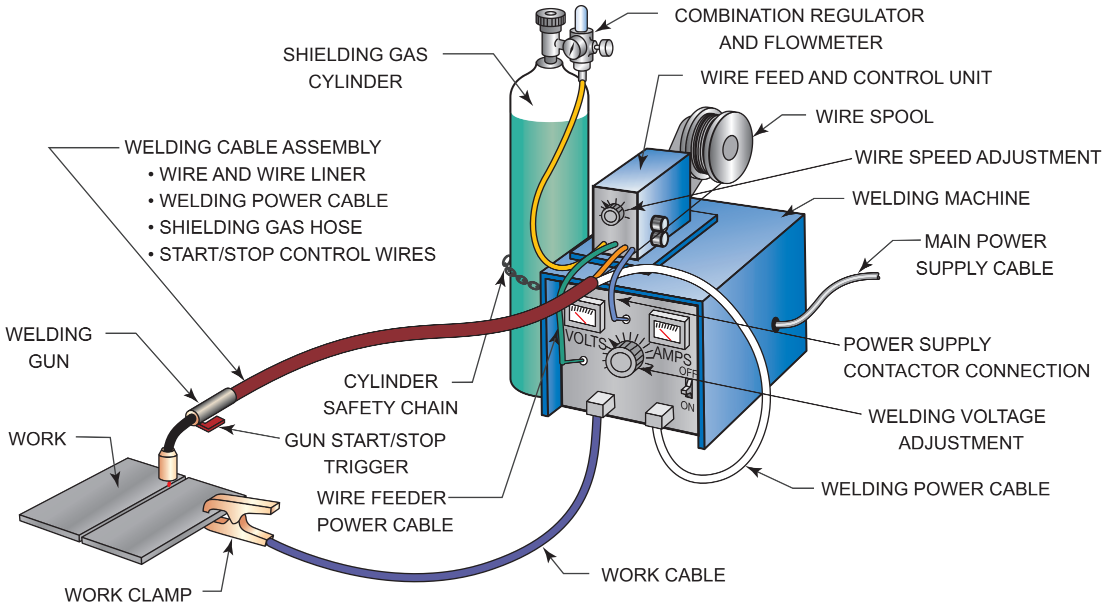


FIGURE 13-1 Basic FCA welding equipment identification.

field, manufacturers' literature is not always available for the equipment you are asked to use. It is therefore important to have a good general knowledge and understanding of the setup procedure for FCA welding equipment. **Figure 13-1** shows all of the various components that make up an FCA welding station.

CAUTION

FCA welding produces a lot of ultraviolet light, heat, sparks, slag, and welding fumes. Proper personal protective clothing and special protective clothing must be worn to prevent burns from the ultraviolet light and hot weld metal. Eye protection must be worn to prevent injury from flying sparks and slag. Forced ventilation and possibly a respirator must be used to prevent fume-related injuries. Refer to the safety precautions provided by the equipment and electrode manufacturers and to Chapter 2 (Safety in Welding) for additional safety help.

PRACTICES

The practices in this chapter are grouped according to those requiring similar techniques and setups. Plate welds are covered first, then sheet metal. The practices start with 1/4-in. (6-mm) mild steel plates; they are used because they require the least preparation times. The thicker 3/8-in. (9.5-mm) plates provide the basics of practicing groove welding. The 3/4-in. (19-mm) and thicker plates are used to develop the skill required to pass the unlimited thickness test often given to FCA welders. Sheet metal is grouped together because it presents a unique set of learning skills.

The major skill required for making consistently acceptable FCA welds is the ability to set up the welding system. Changes such as variations in material thickness, position, and type of joint require changes both in technique and setup. A correctly set-up FCA welding station can, in many cases, be operated by a less skilled welder. Often the only difference between a welder earning a minimum wage and one earning the maximum wage is the ability to correct machine setups.

For several reasons the FCA welding practice plates will be larger than most other practice plates. Welding heat and welding speed are the major factors that necessitate this increased size. FCA welding is both high-energy and fast, and the welding energy (heat) input is so great that small practice plates may glow red by the end of a single weld pass. This would seriously affect the weld quality. To prevent this from happening, wider plates are used. Because of the higher welding speeds, longer plates are usually used.

Plates less than 1/2 in. (13 mm) thick will be 12 in. (305 mm) long for most practices. In addition to controlling the heat buildup, the longer plates are needed to give the welder enough time to practice welding. Learning to make longer welds is a skill that must also be practiced because the FCA welding process is used in industry to make long production welds.

Plates thicker than 1/2 in. (13 mm) can be shorter than 12 in. (305 mm). Most codes usually allow test plates of "unlimited thickness" to be as short as 7 in. (178 mm).

PRACTICE 13-1

FCAW Equipment Setup

For this practice, you will need a semiautomatic welding power source approved for FCA welding, welding gun, electrode feed unit, electrode supply, shielding gas supply, shielding gas flowmeter regulator, electrode conduit, power and work leads, shielding gas hoses (if required), assorted hand tools, spare parts, and any other required materials. In this practice, you will demonstrate to a group of students and your instructor how to properly set up an FCA welding station. Some manufacturers include detailed setup instructions with their equipment. If such instructions are available for your equipment, follow them. Otherwise, use the following instructions.

If the shielding gas is to be used and it comes from a cylinder, then the cylinder must be chained securely in place before the valve protection cap is removed, **Figure 13-2**. Stand to one side of the cylinder and quickly crack the valve to blow out any dirt in the valve before the flowmeter regulator is attached, **Figure 13-3**. Attach the correct hose from the regulator to the "gas-in" connection on the electrode feed unit or machine.

Install the reel of electrode (welding wire) on the holder and secure it, **Figure 13-4**. Check the feed roller size to ensure that it matches the wire size, **Figure 13-5**. The **conduit liner** size should be checked for compatibility with the wire size. Connect the conduit to the feed unit. The conduit or an extension should be aligned with the groove in the roller and set as close to the roller as possible without touching, **Figure 13-6**. Misalignment at this point can contribute to a bird's nest, **Figure 13-7**. Bird-nesting of the electrode wire, so called because it looks like a bird's nest, results when the feed roller pushes the wire into a tangled ball because the wire would not go through the outfeed side conduit.

Be sure the power is off before attaching the welding cables. The electrode and work leads should be attached to the proper terminals. The electrode lead should be attached to the electrode or positive (+). If necessary, it is also attached to the power cable part of the gun lead. The work lead should be attached to the work or negative (−).

The shielding "gas-out" side of the solenoid is then also attached to the gun lead. If a separate splice is required from the gun switch circuit to the feed unit, then it should be connected at this time. Check that the welding contactor circuit is connected from the feed unit to the power source.

The welding cable liner or wire conduit must be securely attached to the gas diffuser and **contact tube** (tip), **Figure 13-8**. The contact tube must be the correct size to match the electrode wire size being used. If a shielding gas is to be used, then a gas nozzle would be attached to

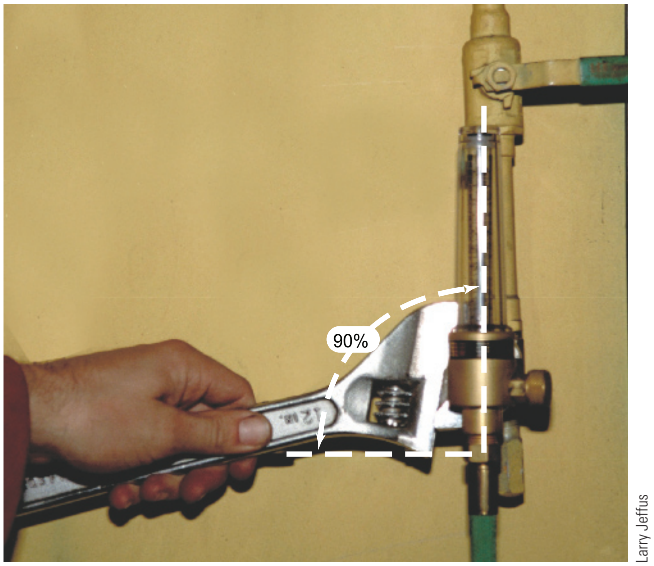


FIGURE 13-3 Attach the flowmeter regulator. Be sure the tube is vertical.

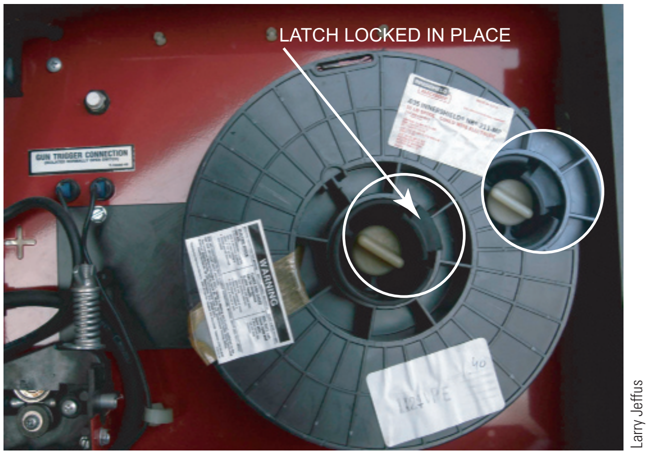


FIGURE 13-4 Wire reel may be secured by a center nut or locking leaver.

FIGURE 13-2 Make sure the gas cylinder is chained securely in place before removing the safety cap.

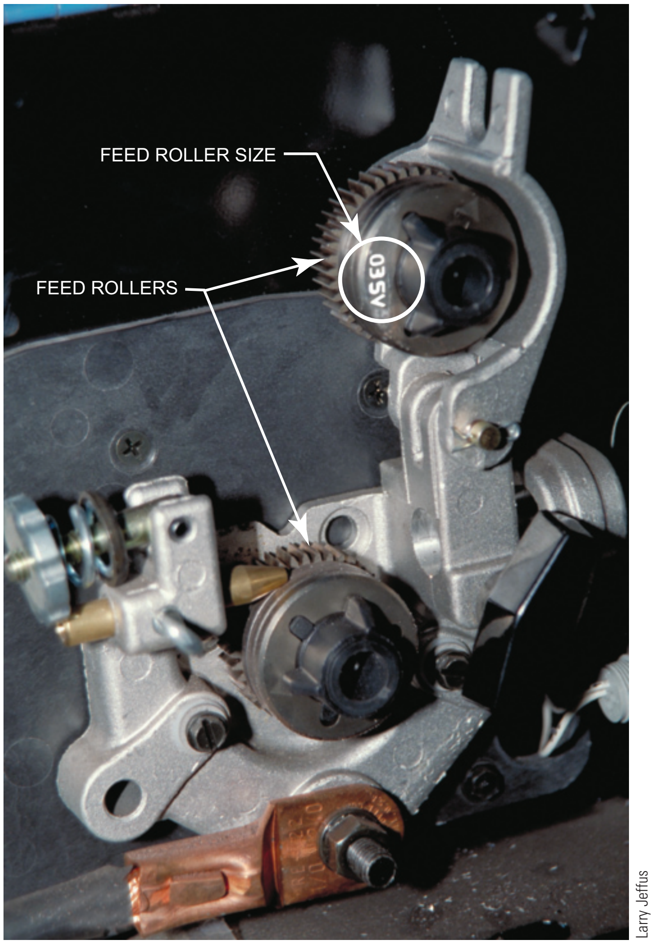


FIGURE 13-5 Check to be certain that the feed rollers are the correct size for the wire being used.

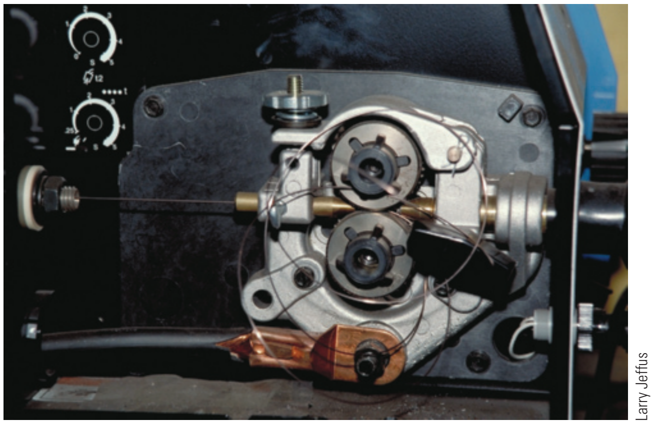


FIGURE 13-7 "Bird's nest" in the filler wire at the feed rollers.

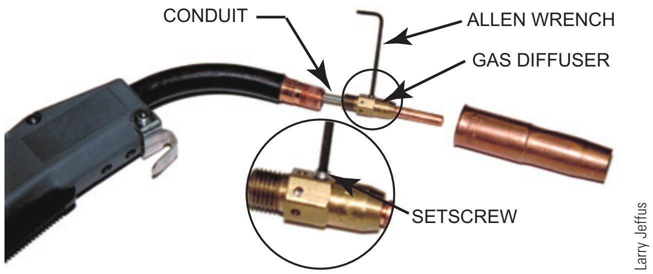


FIGURE 13-8 Securely attach conduit to gas diffuser and contact tube to prevent wire jams caused by misalignment.

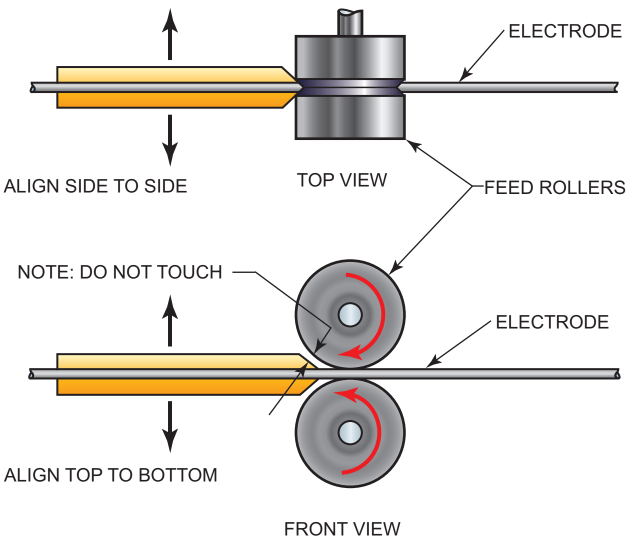


FIGURE 13-6 Feed roller and conduit alignment.

complete the assembly. If a gas nozzle is not needed for a shielding gas, then it may still be installed. Because it is easy for a student to touch the work with the contact tube during welding, an electrical short may occur. This short-out of the contact tube will immediately destroy the tube. Although the gas nozzle may interfere with some visibility, it may be worth the trouble for a new welder. FCA welding is more sensitive to changes in arc voltage than is SMAW (stick) welding. Such variations in FCA welding voltage can dramatically and adversely affect your ability to maintain weld bead control. A loose or poor connection will result in increased circuit resistance and a loss of welding voltage. To be sure you have a good work connection, remove any dirt, rust, oil, or other surface contamination at the point the work clamp is connected to the weldment.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 13-2

Threading FCAW Wire

Using the FCAW machine that was properly assembled in Practice 13-1, you will turn on the machine and thread the electrode wire through the system.

Check that the unit is assembled correctly according to the manufacturer's specifications. Switch on the power

and check the gun switch circuit by depressing the switch. The power source relays, feed relays, gas solenoid, and feed motor should all activate.

Cut off the end of the electrode wire if it is bent. When working with the wire, be sure to hold it tightly. The wire will become tangled if it is released. The wire has a natural curl known as *cast*. Straighten out approximately 12 in. (300 mm) of the curl to make threading easier.

Separate the wire **feed rollers** and push the wire first through the guides, then between the rollers, and finally into the conduit liner, **Figure 13-9**. Reset the rollers so there is a slight amount of compression on the wire, **Figure 13-10**. Set the **wire-feed speed** control to a slow speed. Hold the welding gun so that the electrode conduit and cable are as straight as possible.

Press the gun switch. Pressing the gun switch to start the wire feeder is called triggering the gun. The wire should start feeding into the liner. Watch to make certain that the wire feeds smoothly and release the gun switch as soon as the end comes through the gun.

If the wire stops feeding before it reaches the end of the gun, stop and check the system. If no obvious problem can be found, then mark the wire with tape and remove it from the gun. It then can be held next to the system to determine the location of the problem.

With the wire feed running, adjust the feed roller compression so that the wire reel can be stopped easily by a slight pressure. Roller pressure that is too light will cause the wire to feed erratically. Pressure that is too high can crush some wires, causing some flux to be dropped inside the wire liner. If this happens, then you will have a continual problem with the wire not feeding smoothly or jamming.

With the feed running, adjust the spool drag so that the reel stops when the feed stops. The reel should not coast to a stop because the wire can be snagged easily. Also, when the feed restarts, a jolt occurs when the slack in the wire is taken up. This jolt can be enough to momentarily stop the wire, possibly causing a discontinuity in the weld.

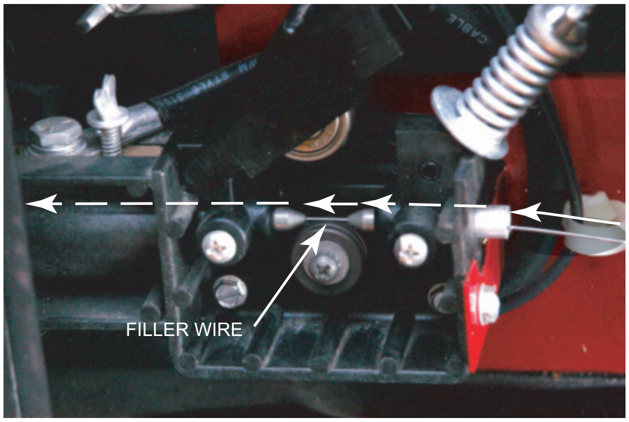


FIGURE 13-9 Push the wire through the guides by hand.

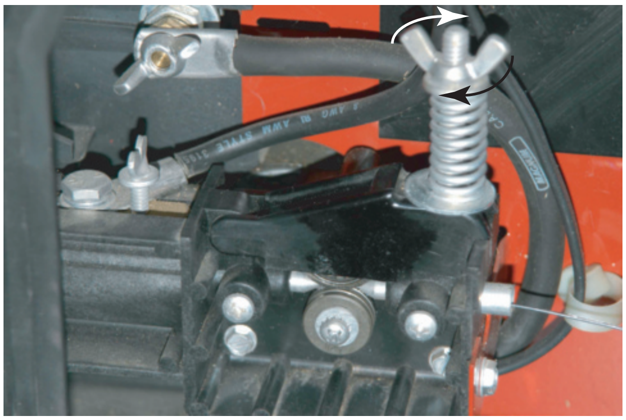


FIGURE 13-10 Adjust the wire feed tensioner.

THINK GREEN

Minimize Wasted Metal

Most of the welding practice plates for FCA welding are 12 in. (305 mm) long. The longer plate lengths are needed because of the higher welding speeds associated with FCA welding. To save metal you should cut out old welds from completed practices so the plates can be reused.

When the test runs are completed, the wire can be either rewound or cut off. Some wire-feed units have a retract button. This allows the feed driver to reverse and retract the wire automatically. To rewind the wire on units without this retract feature, release the rollers and turn them backward by hand. If the machine will not allow the feed rollers to be released without upsetting the tension, you must cut the wire. Some wire reels have covers to prevent the collection of dust, dirt, and metal filings on the wire, **Figure 13-11**.

Complete a copy of the “Student Welding Report” listed in Appendix I or provided by your instructor. ◆

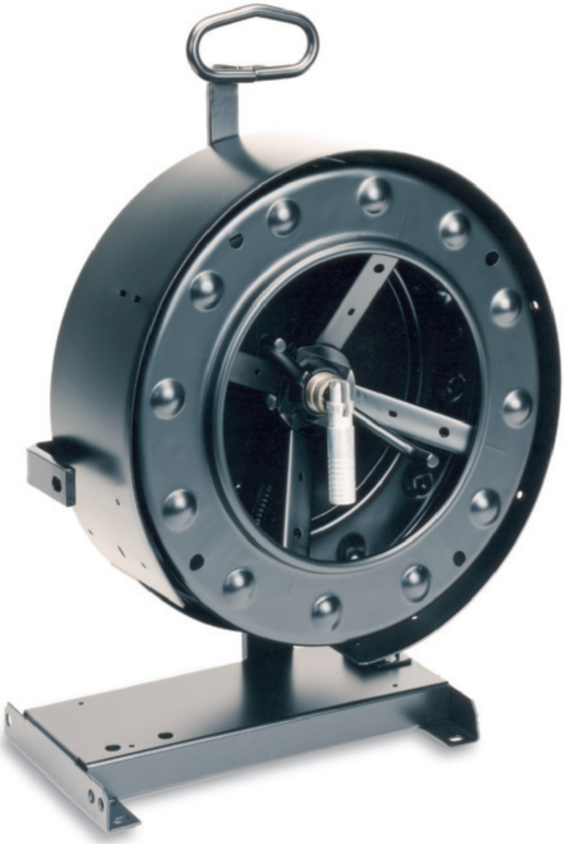
FLAT-POSITION WELDS

PRACTICE 13-3

Stringer Beads Flat Position

Using a properly set-up and adjusted FCA welding machine, **Table 13-1**, proper safety protection, 0.035-in. and/or 0.045-in. (0.9-mm and/or 1.2-mm) diameter E70T-1 and/or E70T-5 electrodes, and one or more pieces of mild steel plate 12 in. (305 mm) long and 1/4 in. (6 mm) thick or thicker, you will make a stringer bead weld in the flat position, **Figure 13-12**.

Starting at one end of the plate and using a dragging technique, make a weld bead along the entire 12-in. (305-mm) length of the metal. After the weld is complete, check its appearance. Make any needed changes to correct



Courtesy of Lincoln Electric Company

(A)

Courtesy of Lincoln Electric Company

(B)

FIGURE 13-11 (A) Covered wire reel. (B) Wire cover on a dual wire feedsystem.

Electrode		Welding Power			Shielding Gas		Base Metal	
Type	Size	Amps	Wire-Feed Speed IPM (cm/min)	Volts	Type	Flow	Type	Thickness
E70T-1	0.035 in. (0.9 mm)	130 to 150	288 to 380 (732 to 975)	22 to 25	None	n/a	Low carbon steel	1/4 in. to 3/4 in. (6 mm to 19 mm)
E70T-1	0.045 in. (1.2 mm)	150 to 210	200 to 300 (508 to 762)	28 to 29	None	n/a	Low carbon steel	1/4 in. to 3/4 in. (6 mm to 19 mm)
E70T-1	0.052 in. (1.4 mm)	150 to 300	150 to 350 (381 to 889)	25 to 33	None	n/a	Low carbon steel	1/4 in. to 3/4 in. (6 mm to 19 mm)
E70T-1	1/16 in. (1.6 mm)	200 to 400	150 to 300 (381 to 762)	27 to 33	None	n/a	Low carbon steel	1/4 in. to 3/4 in. (6 mm to 19 mm)
E70T-5	0.035 in. (0.9 mm)	130 to 200	288 to 576 (732 to 1463)	20 to 28	75% argon 25% CO_2	30 cfh	Low carbon steel	1/4 in. to 3/4 in. (6 mm to 19 mm)
E70T-5	0.045 in. (1.2 mm)	150 to 250	200 to 400 (508 to 1016)	23 to 29	75% argon 25% CO_2	35 cfh	Low carbon steel	1/4 in. to 3/4 in. (6 mm to 19 mm)
E70T-5	0.052 in. (1.4 mm)	150 to 300	150 to 350 (381 to 889)	21 to 32	75% argon 25% CO_2	35 cfh	Low carbon steel	1/4 in. to 3/4 in. (6 mm to 19 mm)
E70T-5	1/16 in. (1.6 mm)	180 to 400	145 to 350 (368 to 889)	21 to 34	75% argon 25% CO_2	40 cfh	Low carbon steel	1/4 in. to 3/4 in. (6 mm to 19 mm)

TABLE 13-1 FCA Welding Parameters for Use if Specific Settings Are Unavailable from Electrode Manufacturer

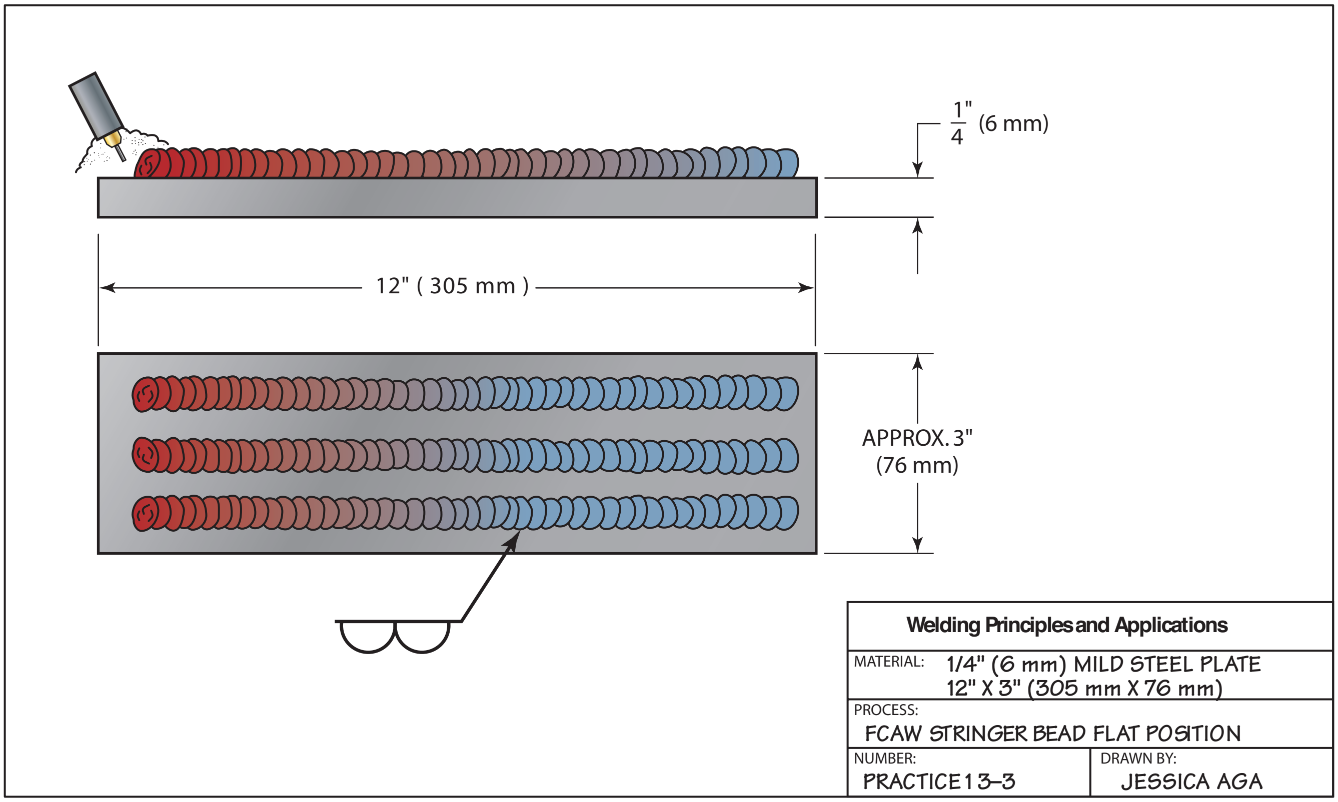


FIGURE 13-12 FCAW stringer bead, 1/4-in. mild steel flat position.

the weld. Repeat the weld and make additional adjustments. After the machine is set, start to work on improving the straightness and uniformity of the weld. Use weave patterns of different widths and straight stringers without weaving.

Repeat with both classifications of electrodes as needed until beads can be made straight, uniform, and free from any visual defects. Turn off the welding machine and shielding gas and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

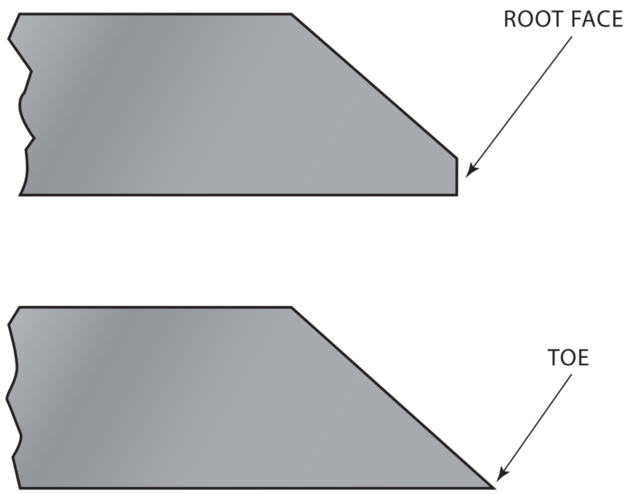


FIGURE 13-13 A beveled joint may or may not have a flat surface, called a root face.

SQUARE-GROOVE WELDS

One advantage of FCA welding is the ability to make 100% joint penetrating welds without beveling the edges of the plates. These full joint penetrating welds can be made in plates that are 1/4 in. (6 mm) or less in thickness. Welding on thicker plates risks the possibility of a lack of fusion on both sides of the **root face**, **Figure 13-13**.

There are several disadvantages of having to bevel a plate before welding:

- Beveling the edge of a plate adds an operation to the fabrication process.
- More filler metal and welding time are required to fill a beveled joint than are required to make a square-jointed weld.
- Beveled joints have more heat from the thermal beveling and additional welding required to fill the groove. The lower heat input to the square joint means less distortion.

The major disadvantage of making square-jointed welds is that as the plate thickness approaches 1/4 in. (6 mm) or the weld is out of position, a much higher level of skill is required. The skill required to make quality

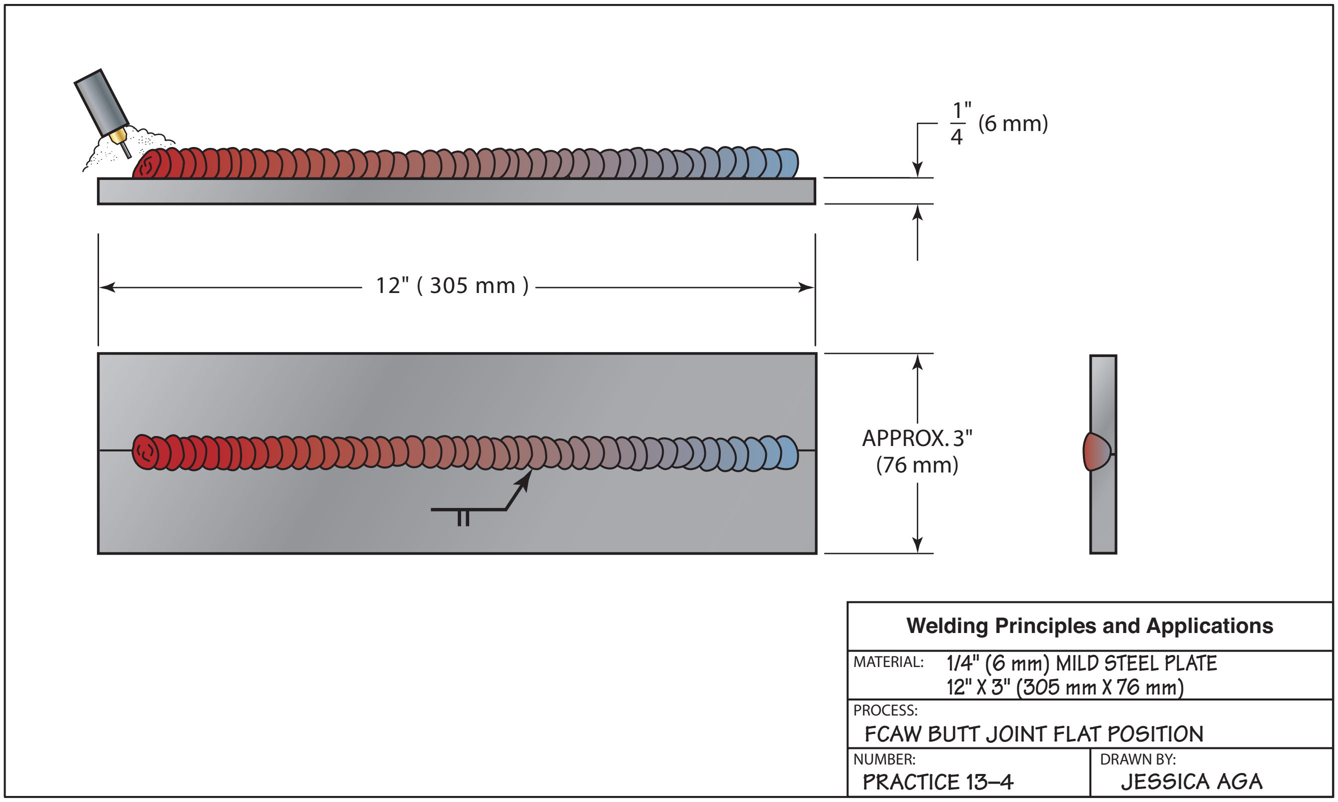


FIGURE 13-14 FCAW butt joint, 1/4-in. (6-mm) mild steel flat position.

square welds can be acquired by practicing on thinner metal. It is much easier to make this type of weld in 1/8-in. (3-mm)-thick metal and then move up in thickness as your skills improve.

PRACTICE 13-4

Square Butt Joint 1G

Using a properly set-up and adjusted FCA welding machine, proper safety protection, 0.035-in. and/or 0.045-in. (0.9-mm and/or 1.2-mm) diameter E70T-1 and/or E70T-5 electrodes, and two or more pieces of mild steel plate 12 in. (305 mm) long and 1/4 in. (6 mm) thick or less in thickness, you will make a groove weld in the flat position, **Figure 13-14**.

- Tack weld the plates together and place them in position to be welded.
- Starting at one end, run a bead along the joint. Watch the molten weld pool and bead for signs that a change in technique may be required.
- Make any needed changes as the weld progresses to produce a uniform weld.

Repeat with both classifications of electrodes as needed until defect-free welds can be consistently made in the 1/4-in. (6-mm)-thick plate. Turn off the welding machine and shielding gas and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

V-GROOVE AND BEVEL-GROOVE WELDS

For speed and economy, engineers try to avoid specifying welds that require beveling the edges of plates, but this is not always possible. Any time the metal being welded is thicker than 1/4 in. (6 mm) and a 100% joint penetration weld is required, the edges of the plate must be prepared with a bevel. Fortunately, FCA welding allows a narrower groove to be made and still achieve a thorough thickness weld, **Figure 13-15**.

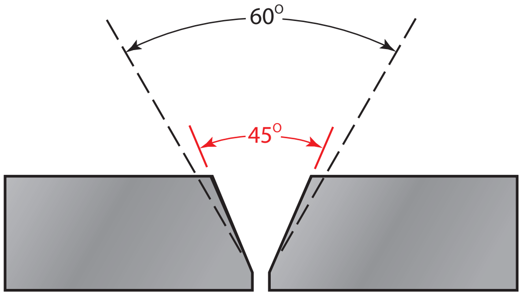


FIGURE 13-15 A smaller groove angle reduces both weld time and filler metal required to make the weld.

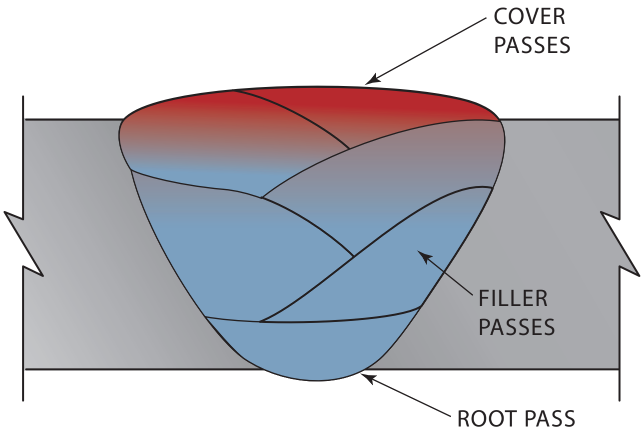


FIGURE 13-16 The three different types of weld passes that make up a weld.

All FCA groove welds are made using three different types of weld passes, **Figure 13-16**.

- *Root pass:* The first weld bead of a multiple pass weld. The root pass fuses the two parts together and establishes the depth of weld metal penetration.
- *Filler pass:* Made after the root pass is completed and used to fill the groove with weld metal. More than one pass is often required.
- *Cover pass:* The last weld pass on a multipass weld. The cover pass may be made with one or more welds. It must be uniform in width, reinforcement, and appearance.

Root Pass

A good root pass is needed to obtain a sound weld. The root may be either open or closed using a backing strip, **Figure 13-17**.

The backing strips are usually made from a piece of 1/4-in. (6-mm)-thick, 1-in. (25-mm)-wide metal that should be 2 in. (50 mm) longer than the base plates to serve as startup and runoff tabs for the weld. The strip is attached to the plate by tack welds made on the sides of the strip, **Figure 13-18**.

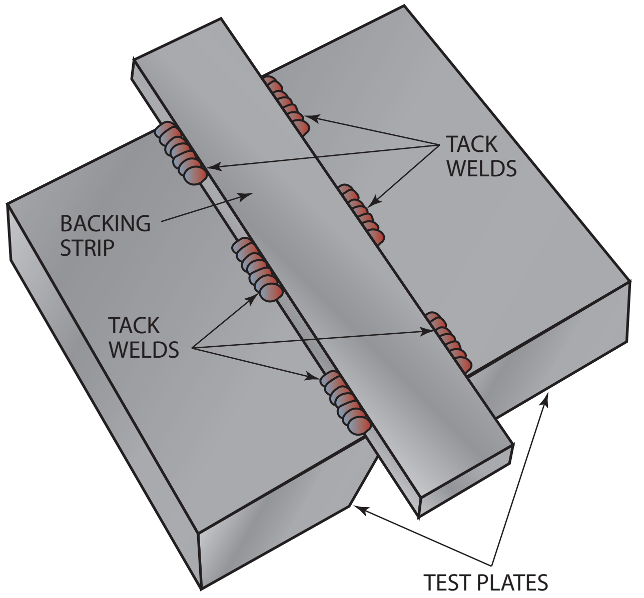


FIGURE 13-18 Securely tack weld the backing strip to the test plates.

Most production welds do not use backing strips, so they are made as open root welds. However, because of the difficulty in controlling FCA weld's root weld face contours, open root joints are often avoided on **critical welds**. If an open root weld is needed because of weldment design, then the root pass may be put in with a GMAW or SMAW electrode or the root face of the FCA weld can be retouched by grinding and/or back welding.

Care must be taken with any root pass to not have the weld face too convex, **Figure 13-19**. Convex weld faces tend to trap slag along the toe of the weld. FCA weld slag can be extremely difficult to remove in this area, especially if there is any undercutting. To avoid this, adjust the welding power settings, speed, and weave pattern so that a flat or slightly concave weld face is produced, **Figure 13-20**.

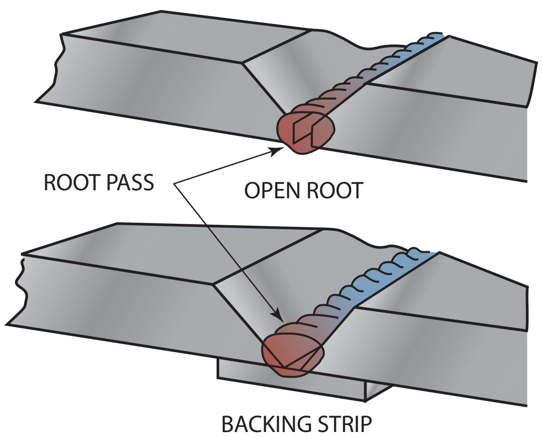


FIGURE 13-17 Root pass maximum deposit 1/4 in. (6 mm) thick.

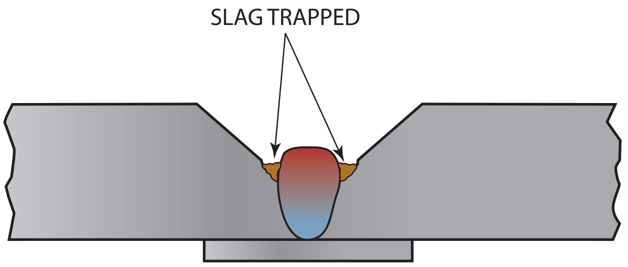


FIGURE 13-19 Slag trapped beside weld bead is hard to remove.

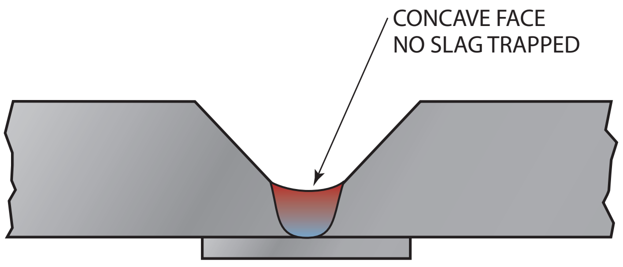


FIGURE 13-20 Flat or concave weld faces are easier to clean off.

Filler Pass

Filler passes are made with either **stringer beads** or **weave beads** for flat or vertically positioned welds, but stringer beads work best for horizontal and overhead-positioned welds. When multiple pass filler welds are required, each weld bead must overlap the others along the edges. Edges should overlap smoothly enough so that the finished bead is uniform, **Figure 13-21**. Stringer beads usually overlap approximately 25% to 50%, and weave beads overlap approximately 10% to 25%.

Each weld bead must be cleaned before the next bead is started. The filler pass ends when the groove has been filled to a level just below the plate surface.

Cover Pass

The cover pass may or may not simply be a continuation of the weld beads used to make the filler pass(es). The major difference between the filler pass and the cover pass is the weld face importance. Keeping the face and toe of the cover pass uniform in width, reinforcement, and appearance and defect-free is essential. Most welds are not tested beyond a visual inspection. For that reason the appearance might be the only factor used for accepting or rejecting welds.

The cover pass must meet a strict visual inspection standard. The visual inspection checks to see that the weld is uniform in width and reinforcement. There should be no arc strikes on the plate other than those on the weld itself. The weld must be free of both incomplete fusion and cracks. The weld must be free of overlap, and undercut must not exceed either 10% of the base metal or 1/32 in. (0.8 mm), whichever is less. Reinforcement must have a smooth transition with the base plate and must be no higher than 1/8 in. (3 mm), **Figure 13-22**.

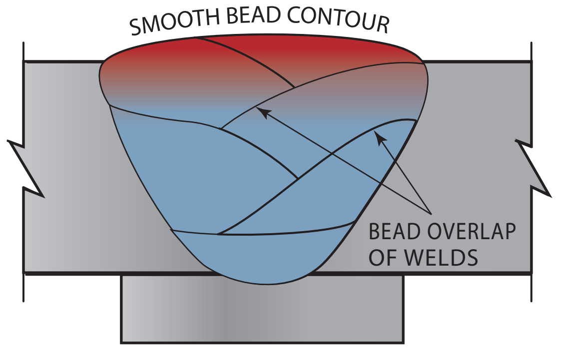


FIGURE 13-21 The surface of a multipass weld should be as smooth as if it were made by one weld.

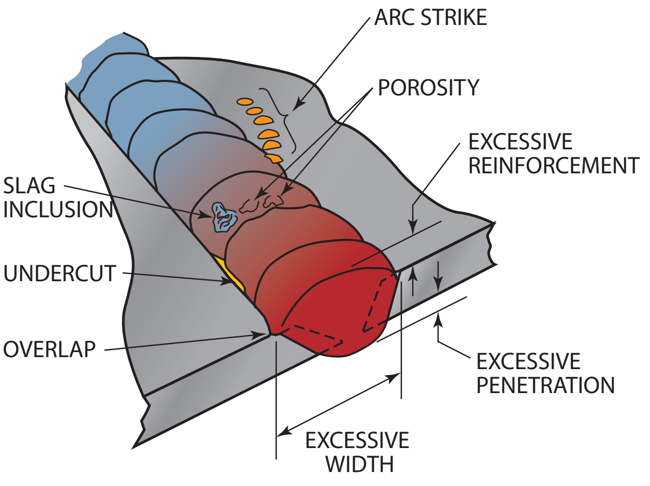


FIGURE 13-22 Common discontinuities found during a visual examination.

PRACTICE 13-5

V-Groove Butt Joint 1G

Using a properly set-up and adjusted FCA welding machine, Table 13-1, proper safety protection, 0.035 in. and/or 0.045 in. (0.9 mm and/or 1.2 mm) diameter E70T-1 and/or E70T-5 electrodes, two or more pieces of mild steel plate 12 in. (305 mm) long and 3/8 in. (9.5 mm) thick, two or more pieces of mild steel plate 7-in. (178-mm)-long and 3/4-in. (19-mm)-thick thick beveled plate, and 14-in.-long and 9-in. (355-mm and 230-mm)-long 1-in. (25-mm)-wide and 1/4-in. (6-mm)-thick backing strips, you will make a V-groove welds in the flat position, **Figure 13-23**.

Tack weld the backing strip to the plates. There should be a root gap between the plates that measures approximately 1/8 in. (3 mm). The beveled surface can be made with or without a root face, **Figure 13-24**.

Place the test plates in position at a comfortable height and location. Be sure you have complete and free movement along the full length of the weld joint. It is often a good idea to make a practice pass along the joint with the welding gun without power to make sure nothing will interfere with your making the weld. Be sure the welding cable is free and will not get caught on anything during the weld.

The backing strip is 2 in. longer than the test plate, so the weld can be started and ended outside the groove on

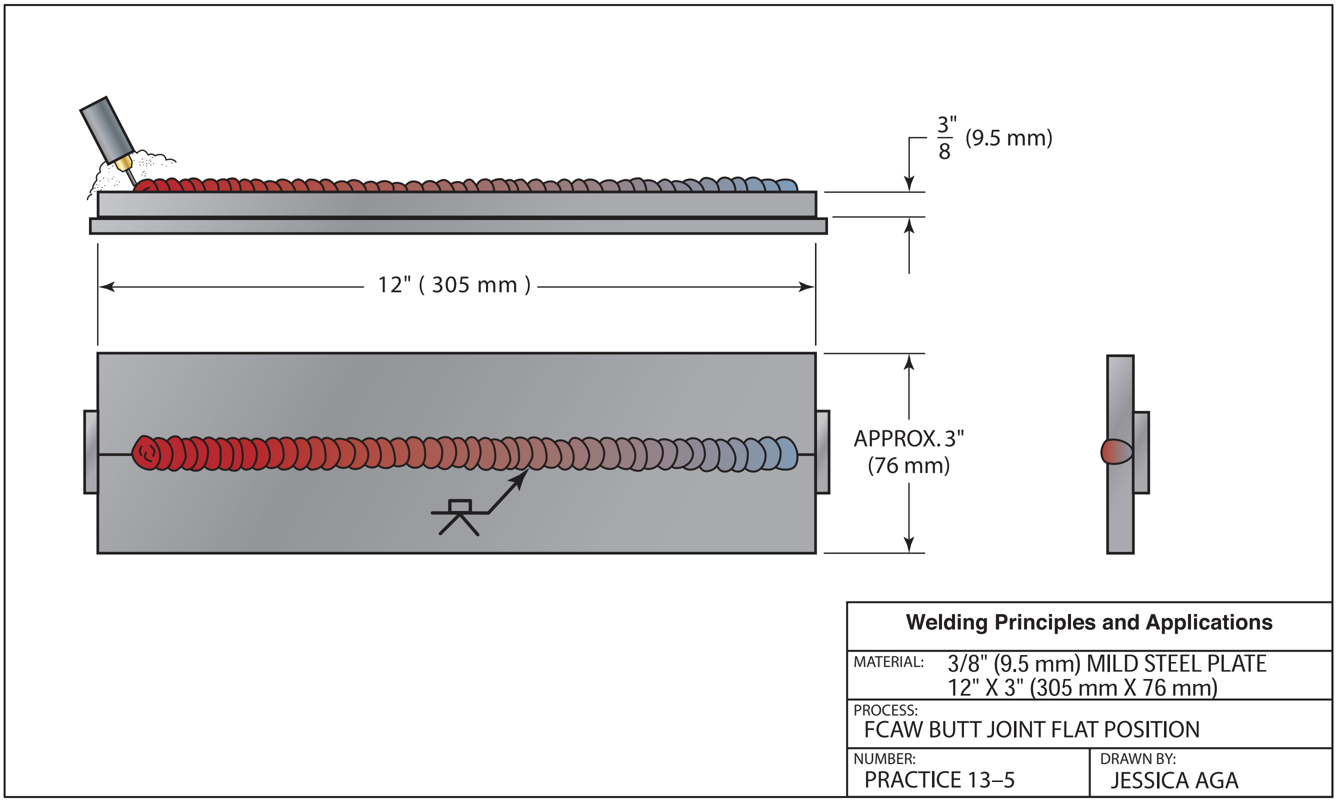


FIGURE 13-23 FCAW butt joint, 3/8-in. (9.5-mm) mild steel flat position.

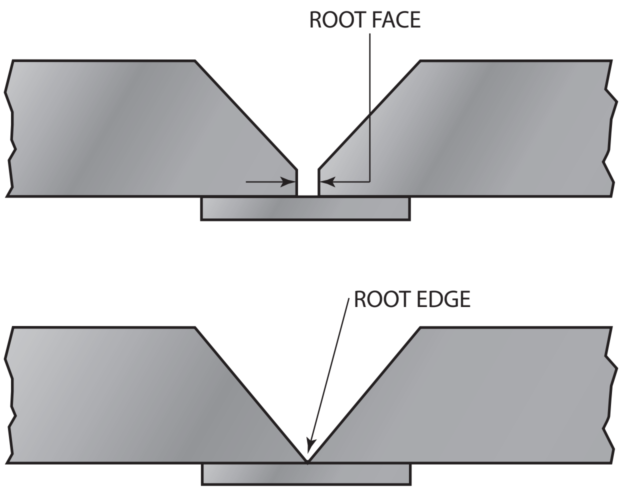


FIGURE 13-24 Groove layout with and without a root face.

FIGURE 13-25 Run-off tabs help control possible underfill or burn back at the starting and stopping points of a groove weld.

the backing strip tab, **Figure 13-25**. This is done so that the arc is smooth and the molten weld pool size is established at the beginning of the groove. Continue the weld out onto the tab at the outer end of the groove. This process ensures that the end of the groove is completely filled with weld.

Repeat with both classifications of electrodes as needed until consistently defect-free welds can be made. Turn off the welding machine and shielding gas and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

FILLET WELDS

A fillet weld is the type of weld made on the **lap joint** and **tee joint**. It should be built up equal to the thickness of the plate, **Figure 13-26**. On thick plates the fillet must be made up of several passes as with a groove

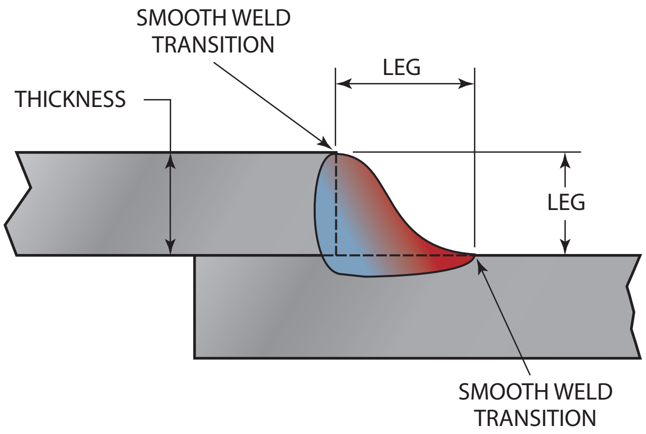


FIGURE 13-26 The legs of a fillet weld should generally be equal to the thickness of the base metal.

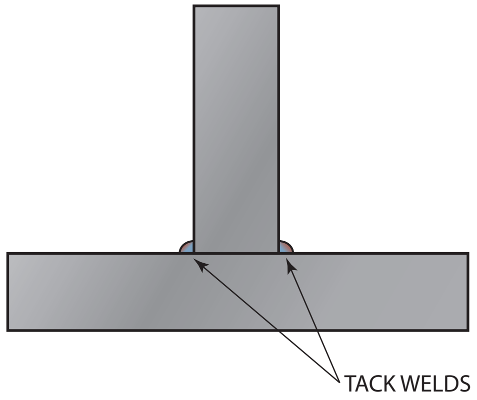


FIGURE 13-28 Tack welding both sides of a tee joint will help keep the tee square for welding.

weld. The difference with a fillet weld is that a smooth transition from the plate surface to the weld is required. If this transition is abrupt, then it can cause stresses that will weaken the joint.

The lap joint is made by overlapping the edges of the plates. They should be held together tightly before tack welding them together. A small tack weld may be added in the center to prevent distortion during welding, **Figure 13-27**. Chip and wire brush the tacks before you start to weld.

The tee joint is made by tack welding one piece of metal on another piece of metal at a right angle, **Figure 13-28**. After the joint is tack welded together, the slag is chipped from the tack welds. If the slag is not removed, then it will cause a slag inclusion in the final weld.

Holding thick plates tightly together on tee joints may cause underbead cracking or lamellar tearing, **Figure 13-29**. On thick plates the weld shrinkage can be great enough to pull the metal apart well below the

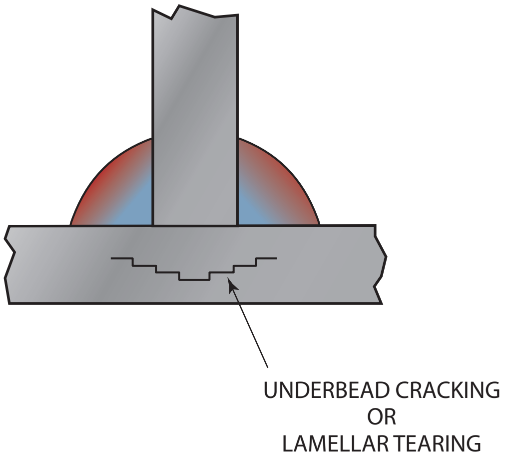


FIGURE 13-29 Underbead cracking or lamellar tearing of the base plate.

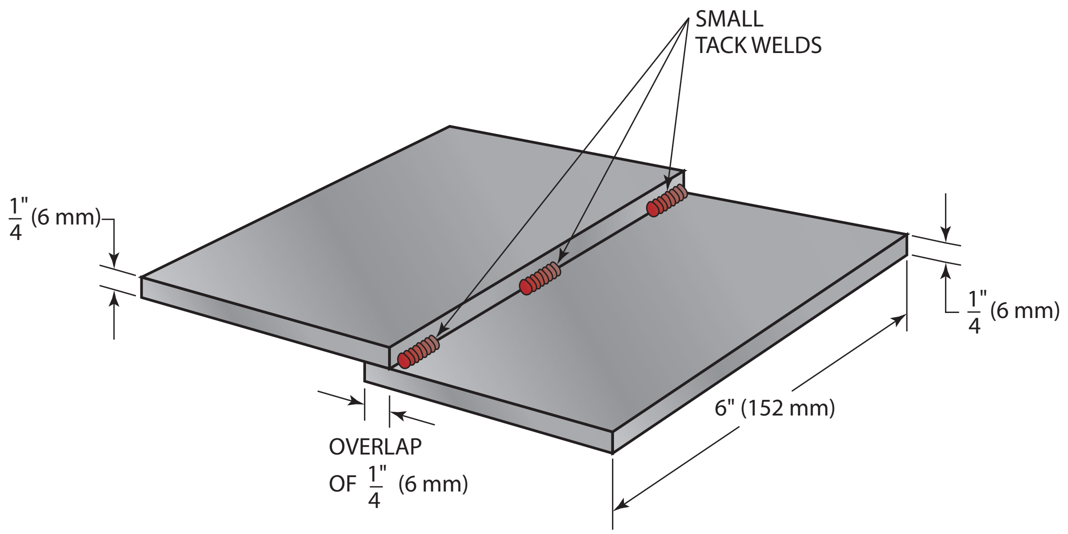


FIGURE 13-27 Tack welding the plates together.

bead or its heat-affected zone. In production welds, cracking can be controlled by not assembling the plates tightly together. The space between the two plates can be set by placing a small wire spacer between them, **Figure 13-30**.

A fillet welded lap or tee joint can be strong if it is welded on both sides, even without having deep penetration, **Figure 13-31**. Some tee joints may be prepared for welding by cutting either a bevel or a J-groove in the vertical plate. This cut is not required for strength but may be necessary because of design limitations. Unless otherwise instructed, most fillet welds will be equal in size to the plates welded. A fillet weld will be as strong as the base plate if the size of the two welds equals the total thickness of the base plate. The weld bead should have a flat or slightly concave appearance to ensure the greatest strength and efficiency, **Figure 13-32**.

The root of fillet welds must be melted to ensure a completely fused joint. A notch along the root of the weld pool is an indication that the root is not being fused together, **Figure 13-33**. To achieve complete root fusion, move the arc to a point as close as possible to the leading edge of the weld pool, **Figure 13-34**. If the arc strikes the unmelted plate ahead of the molten weld pool, it may become erratic, which will increase weld spatter.

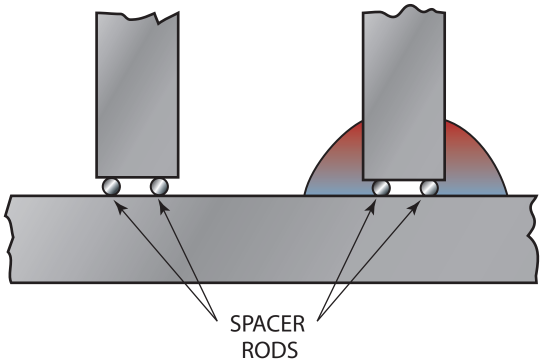


FIGURE 13-30 Base plate cracking can be controlled by placing spacers in the joint before welding.

FIGURE 13-33 Watch the root of the weld bead to be sure there is complete fusion.

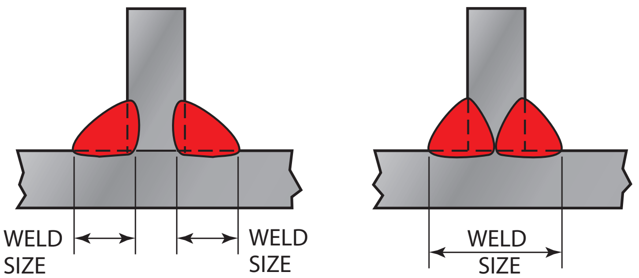


FIGURE 13-31 If the total weld sizes are equal, then both tee joints would have equal strength.

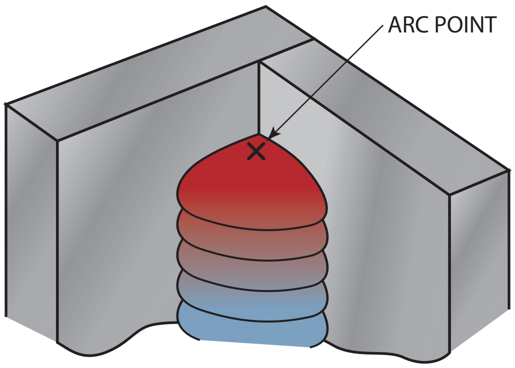


FIGURE 13-34 Moving the arc as close as possible to the leading edge of the weld will provide good root fusion.

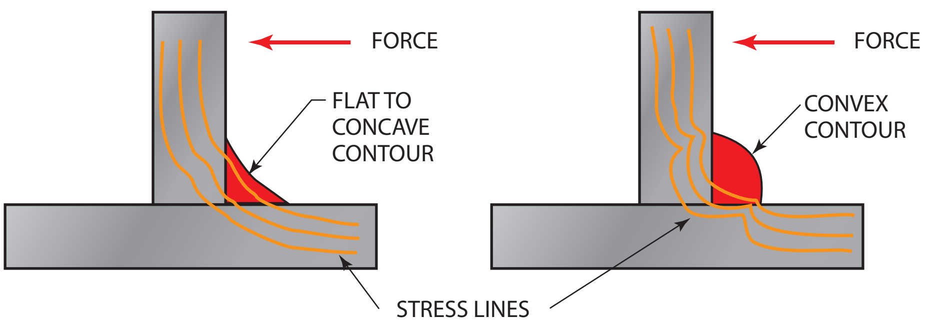


FIGURE 13-32 The stresses are distributed more uniformly through a flat or concave fillet weld.

PRACTICE 13-6

Lap Joint and Tee Joint 1F

Using a properly set up and adjusted FCA welding machine, proper safety protection, 0.035-in. and/or 0.045-in. (0.9-mm and/or 1.2-mm) diameter E70T-1 and/or E70T-5 electrodes, two or more pieces of mild steel plate 12 in. (305 mm) long and 3/8 in. (9.5 mm) thick, and two or more pieces of mild steel plate 7-in. (178-mm)-long and 3/4-in. (19-mm)-thick beveled plates, you will make a fillet welds in the flat position.

Tack weld the pieces of metal together and brace them in position. When making the lap or tee joints in the flat position, the plates must be at a 45° angle so that the surface of the weld will be flat, **Figure 13-35A** and **B**. Starting at one end, make a weld along the entire length of the joint.

Repeat each type of joint with both classifications of electrodes as needed until consistently defect-free welds can be made. Turn off the welding machine and shielding gas and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

VERTICAL WELDS

PRACTICE 13-7

Butt Joint at a 45° Vertical Up Angle

Using a properly set up and adjusted FCA welding machine, proper safety protection, 0.035-in. and/or 0.045-in. (0.9-mm and/or 1.2-mm) diameter E70T-1 and/or E70T-5 electrodes, and two or more pieces of mild steel plate 12 in. (305 mm) long and 1/4 in. (6 mm) thick or thinner, you will increase the plate angle gradually as you develop skill until you are making satisfactory welds in the vertical up position, **Figure 13-36**.

- Start practicing this weld with the plate at a 45° angle.
- Gradually increase the angle of the plate to vertical as skill is gained in welding this joint. A straight stringer bead or slight zigzag will work well on this joint.
- Establish a molten weld pool in the root of the joint.
- Cool, chip, and inspect the weld for uniformity and defects.

It is easier to make a quality weld in the vertical up position if both the **amperage range** and **voltage range** are set at the lower end. This will make the molten weld pool smaller, less fluid, and easier to control. A problem with lower power settings is that the weld bead can often be very convex, **Figure 13-37**. Faster travel speed and/or slightly wider weave patterns can be used to control the bead shape.

Start at the bottom of the plate and hold the welding gun at a slight upward angle to the plate, **Figure 13-38**. Brace yourself, lower your hood, and begin to weld. Depending on the machine settings and type of electrode used, you will make a weave pattern.

If the molten weld pool is large and fluid (hot), use a "C" or "J" weave pattern to allow a longer time for the molten weld pool to cool, **Figure 13-39**. Do not make the weave so long or fast that the electrode is allowed to strike the metal ahead of the molten weld pool. If this happens, spatter increases and a spot or zone of incomplete fusion may occur.

A weld that is high and has little or no fusion is too "cold." Changing the welding technique will not correct this problem. The welder must stop welding and make the needed adjustments to the power supply or electrode feeder. Continue to weld along the entire 12-in. (305-mm) length of plate.

Repeat welds with both electrodes as needed until defect-free welds can be consistently made vertically in the 1/4-in. (6-mm)-thick plate. Turn off the welding machine and shielding gas and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 13-8

Square Groove Butt Joint 3G

Using a properly set up and adjusted FCA welding machine, proper safety protection, 0.035-in. and/or 0.045-in. (0.9-mm and/or 1.2-mm) diameter E70T-1 and/or E70T-5 electrodes, and one or more pieces of mild steel plate 12 in. (305 mm) long and 1/4 in. (6 mm) thick or thinner, you will make a groove weld in the vertical position, **Figure 13-40**.

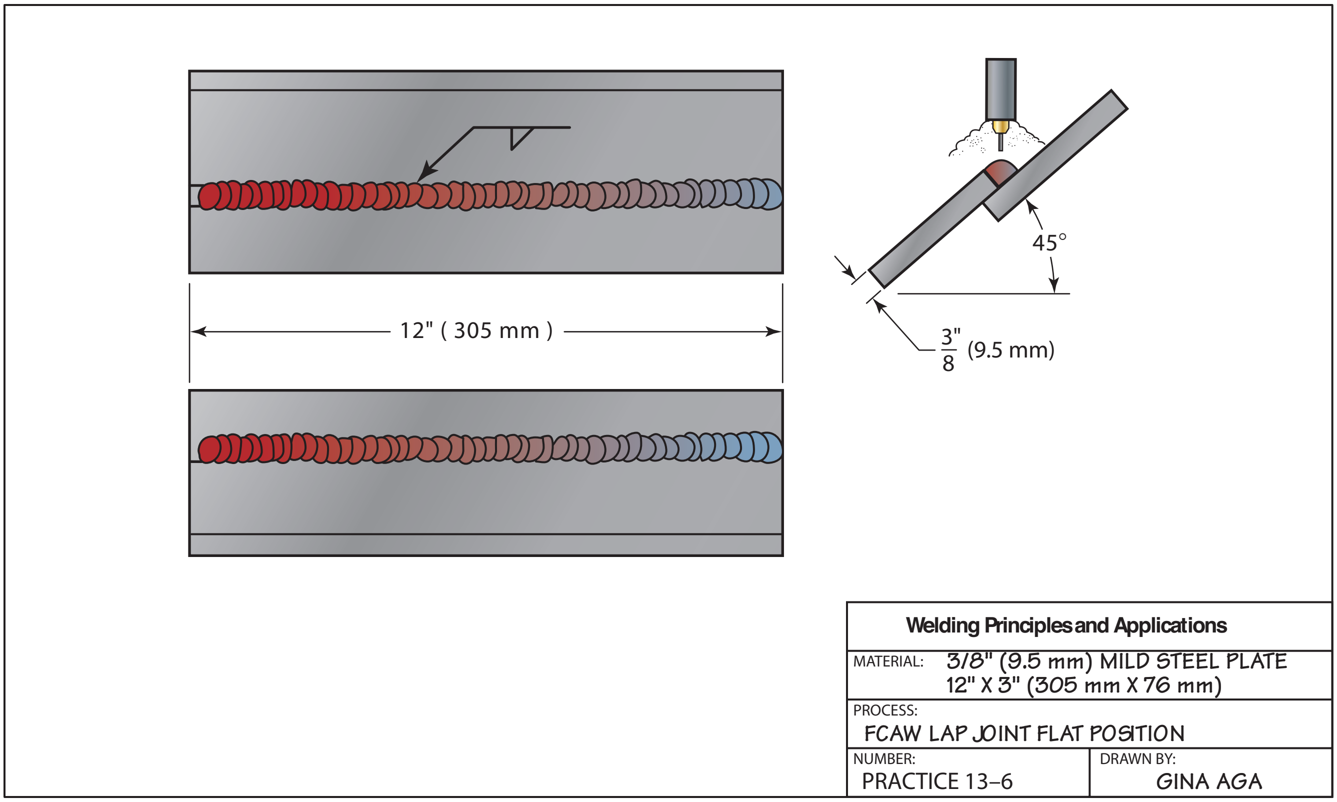
Following the same instructions for the assembly and welding procedure outlined in Practice 13-7, repeat with both classifications of electrodes as needed until defect-free welds can be consistently made in the 1/4-in. (6-mm)-thick plate. Turn off the welding machine and shielding gas and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

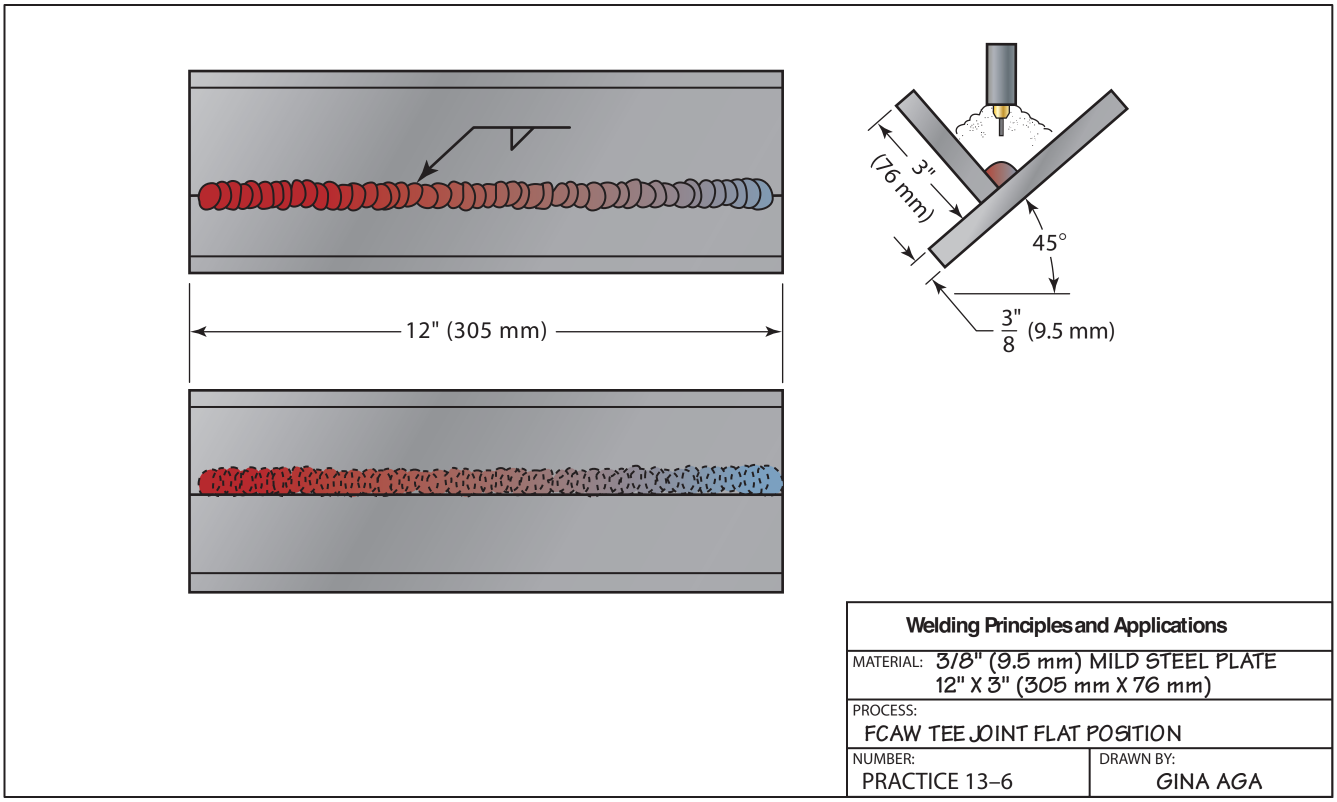
PRACTICE 13-9

V-Groove Butt Joint 3G

Using a properly set up and adjusted FCA welding machine, proper safety protection, 0.035-in. and/or 0.045-in. (0.9-mm and/or 1.2-mm) diameter E70T-1 and/or E70T-5 electrodes, two or more pieces of mild steel plate 12 in. (305 mm) long and 3/8 in. (9.5 mm) thick, two or more pieces of mild steel plate 7 in. (178-mm) long and 3/4-in. (19-mm)-thick beveled plates, and a 14-in.-long and 9-in. (355-mm and 230-mm)-long, 1-in. (25-mm)-wide, and 1/4-in. (6-mm)-thick backing strip, you will make a groove weld in the vertical position.



(A)



(B)

FIGURE 13-35 (A) FCAW lap joint, 3/8-in. (9.5-mm) mild steel flat position. (B) FCAW tee joint, 3/8-in. (9.5-mm) mild steel flat position.

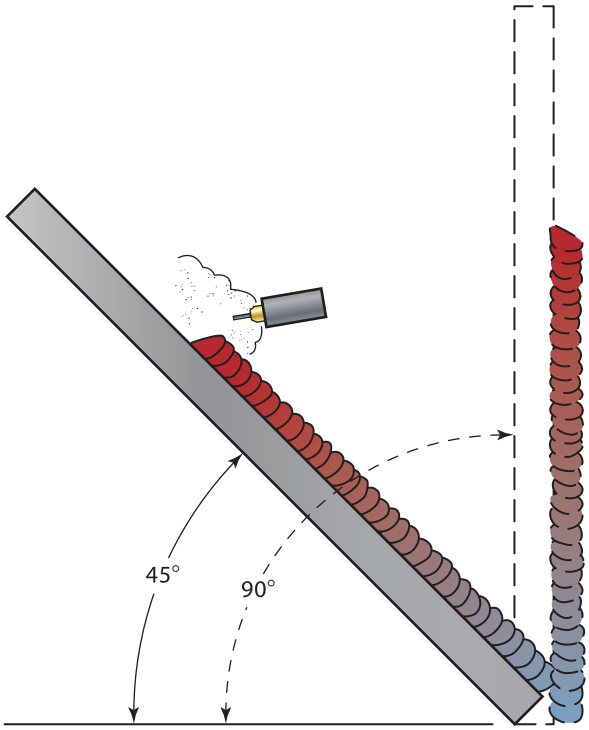


FIGURE 13-36 Start making welds with the plate at a 45° angle. As your skill develops, increase the angle until the plate is vertical.

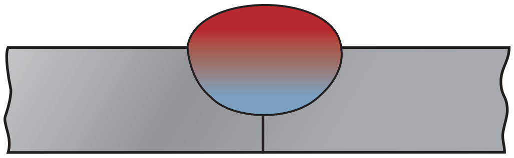


FIGURE 13-37 Low amperage causes too much build up and not enough penetration.

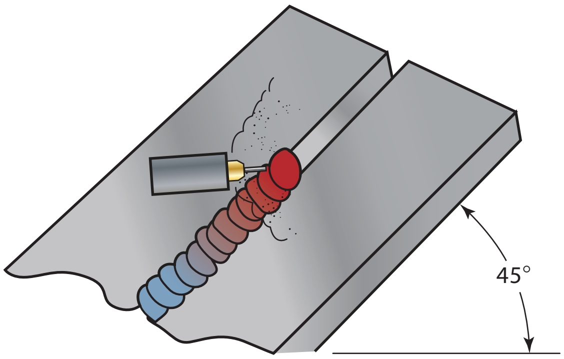


FIGURE 13-38 45° vertical up.

Following the same instructions for the assembly and welding procedure as outlined in Practice 13-7, repeat with both classifications of electrodes as needed until defect-free welds can be consistently made. Turn off the welding machine and shielding gas and clean your work area when you are finished welding.

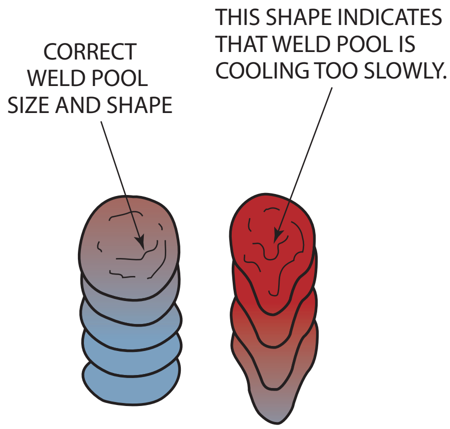


FIGURE 13-39 The shape of the weld pool can indicate the temperature of the surrounding base metal.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 13-10

Fillet Weld Joint at a 45° Vertical Up Angle

Using a properly set up and adjusted FCA welding machine, proper safety protection, 0.035-in. and/or 0.045-in. (0.9-mm and/or 1.2-mm) diameter E70T-1 and/or E70T-5 electrodes, and one or more pieces of mild steel plate 12 in. (305 mm) long and 3/8 in. (9.5 mm) thick, you will increase the plate angle gradually as you develop skill until you are making satisfactory welds in the vertical up position, **Figure 13-41**.

Tack weld the metal pieces together and brace them in position. Check to see that you have free movement along the entire joint to prevent stopping and restarting during the weld. Avoiding stops and starts both speeds up the welding time and eliminates discontinuities.

It is easier to make a quality weld in the vertical up position if both the amperage and voltage are set at the lower end of their ranges. This will make the molten weld pool smaller, less fluid, and easier to control. A problem with the lower power settings is that the weld bead often is very convex. A convex face on a weld bead often makes it more difficult to remove the slag along the toe of the weld.

The weave pattern should allow for adequate fusion on both edges of the joint. Watch the edges to be sure that they are being melted so that adequate fusion and penetration occur.

Repeat with electrodes as needed until defect-free welds can be consistently made vertically. Turn off the welding machine and shielding gas and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

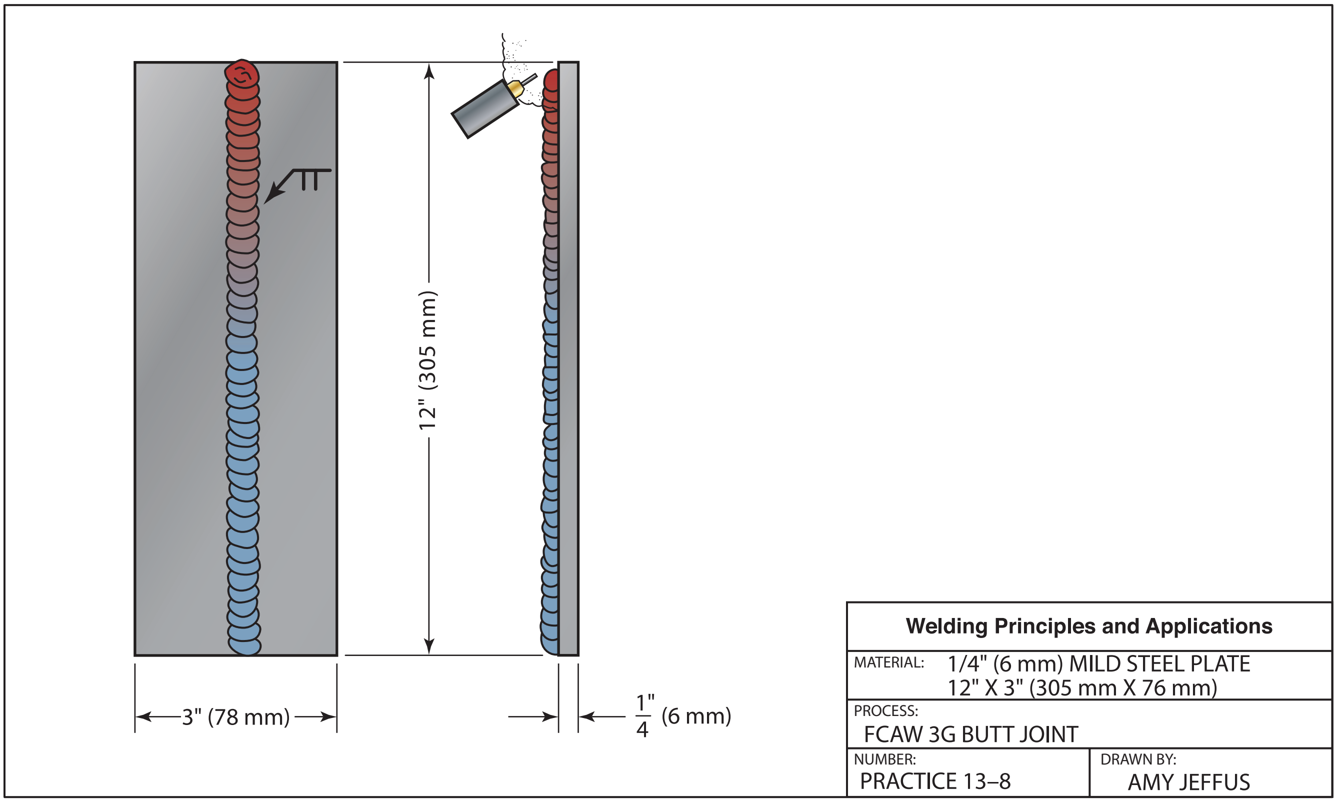


FIGURE 13-40 FCAW 3G butt joint, 1/4-in. (6-mm) mild steel.

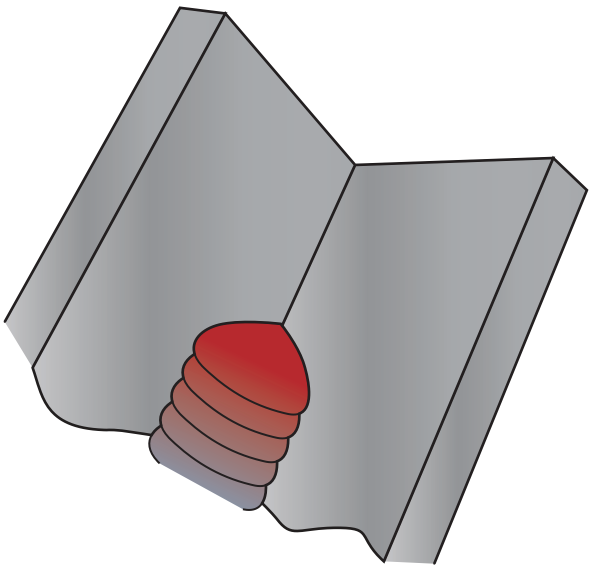


FIGURE 13-41 45° vertical up fillet weld.

PRACTICE 13-11

Lap Joint and Tee Joint 3F

Using a properly set up and adjusted FCA welding machine, proper safety protection, 035-in. and/or 0.045-in. (0.9-mm and/or 1.2-mm) diameter E70T-1 and/or E70T-5 electrodes, two or more pieces of mild steel plate 12 in. (305 mm) long and 3/8 in. (9.5-mm) thick, and two or more pieces of mild steel plate 7 in. (178 mm) long and 3/4-in. (19-mm)-thick beveled plate, you will make a fillet weld in the vertical position.

Following the same instructions for the assembly and welding procedure outlined in Practice 13-10, repeat each type of joint with both classifications of electrodes as needed until defect-free welds can be consistently made. Turn off the welding machine and shielding gas and clean your work area when you are finished welding.

Complete a copy of the “Student Welding Report” listed in Appendix I or provided by your instructor. ◆

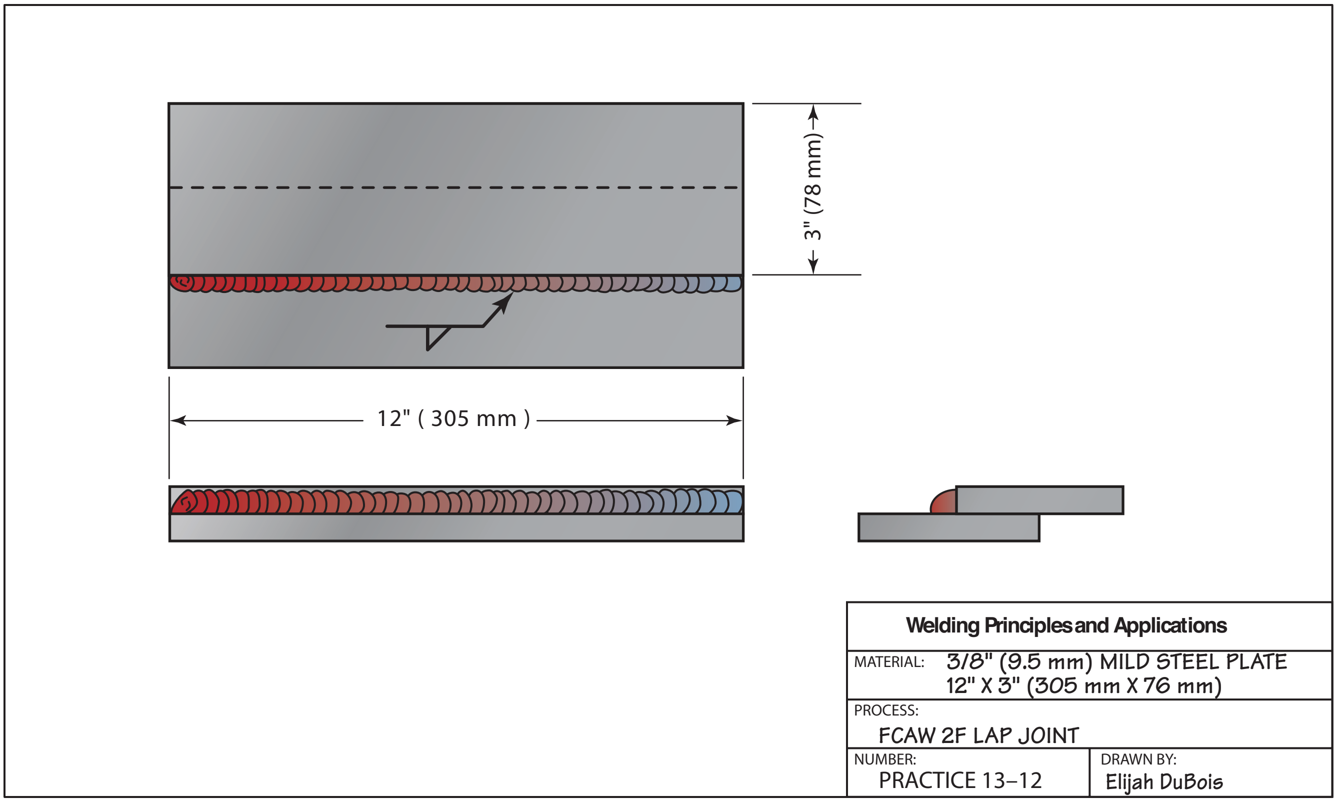
HORIZONTAL WELDS

PRACTICE 13-12

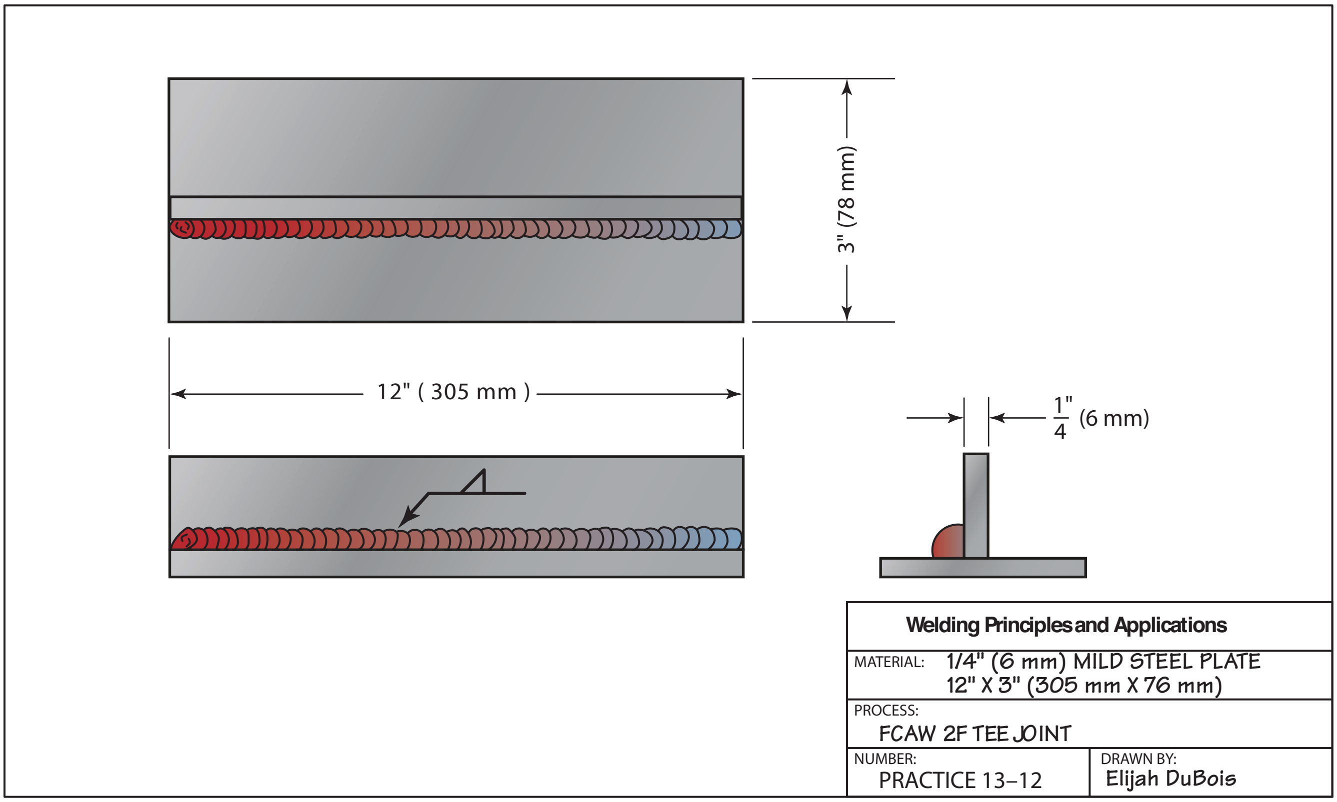
Lap Joint and Tee Joint 2F

Using a properly set up and adjusted FCA welding machine, proper safety protection, 0.035-in. and/or 0.045-in. (0.9-mm and/or 1.2-mm) diameter E70T-1 and/or E70T-5 electrodes, and one or more pieces of mild steel plate 12 in. (305-mm) long and 3/8-in. (9.5-mm)-thick beveled plates, you will make a fillet weld in the horizontal position, **Figure 13-42A** and **B**.

The root weld must be kept small so that its contour can be controlled. A root pass that is too large can trap slag under overlap along the lower edge of the weld,



(A)



(B)

FIGURE 13-42 (A) FCAW 2F lap joint, 3/8-in. (9.5-mm) mild steel. (B) FCAW 2F tee joint, 1/4-in. (6-mm) mild steel.

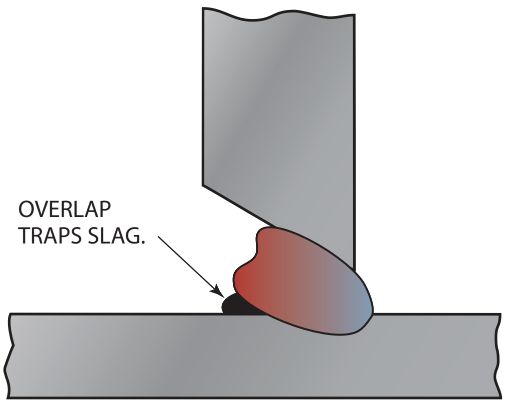


FIGURE 13-43 Slag can be trapped along the side of the root pass.

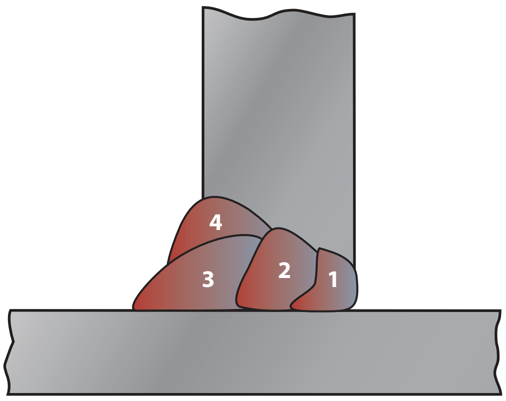


FIGURE 13-44 FCAW weld bead positions for a 100% penetration grooved tee joint.

Figure 13-43. Clean each pass thoroughly before the weld bead is started. Follow the weld bead sequence shown in **Figure 13-44**. Keeping all of the weld beads small will help control their contour.

Repeat each type of joint with both classifications of electrodes as needed until defect-free welds can be consistently made. Turn off the welding machine and shielding gas and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 13-13

Lap and Tee Joint 2F

Using a properly set up and adjusted FCA welding machine, proper safety protection, 0.035-in. and/or up to 1/16-in. (0.9-mm and/or up to 1.6-mm) diameter E70T-1 and/or E70T-5 electrodes, two or more pieces of mild steel plate 12 in. (305 mm) long and 3/8 in. (9.5 mm) thick, and two or more pieces of mild steel plate 7 in. (178-mm) long and 3/4-in. (19-mm)-thick beveled plates, you will make a fillet weld in the horizontal position.

Following the same instructions for the assembly and welding procedure outlined in Practice 13-12, repeat each type of joint with both classifications of electrodes as needed until defect-free welds can be consistently made. Turn off the welding machine and shielding gas and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 13-14

Stringer Bead at a 45° Horizontal Angle

Using a properly set up and adjusted FCA welding machine, proper safety protection, 0.035-in. and/or 0.045-in. (0.9-mm and/or 1.2-mm) diameter E70T-1 and/or E70T-5 electrodes, and one or more pieces of mild steel plate 12 in. (305 mm) long and 1/4 in. (6 mm) thick or thinner, you will increase the plate angle gradually as you develop skill until you are making satisfactory horizontal welds across the vertical face of the plate, **Figure 13-45**.

Repeat the weld using each electrode classification until welds using both electrodes can be made horizontally with uniform bead contours when the plates are vertical. Turn off the welding machine and shielding gas and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 13-15

Bevel Butt Joint 2G

Using a properly set up and adjusted FCA welding machine, proper safety protection, 0.035-in. and/or 0.045-in. (0.9-mm and/or 1.2-mm) diameter E70T-1 and/or E70T-5 electrodes, and two or more pieces of mild steel plate 12 in. (305 mm) long and 1/4 in. (6 mm) thick or thinner, you will make a groove weld in the horizontal position, **Figure 13-46**.

Following the same instructions for the assembly and welding procedure outlined in Practice 13-14, repeat with both classifications of electrodes as needed until defect-free welds can be consistently made in the 1/4-in. (6-mm)-thick plate. Turn off the welding machine and shielding gas and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 13-16

V-Groove Butt Joint 2G

Using a properly set up and adjusted FCA welding machine, proper safety protection, 0.035-in. and/or 0.045-in. (0.9-mm and/or 1.2-mm) diameter E70T-1 and/or E70T-5 electrodes, two or more pieces of mild steel plate 12 in. (305 mm) long and 3/8 in. (9.5-mm) thick

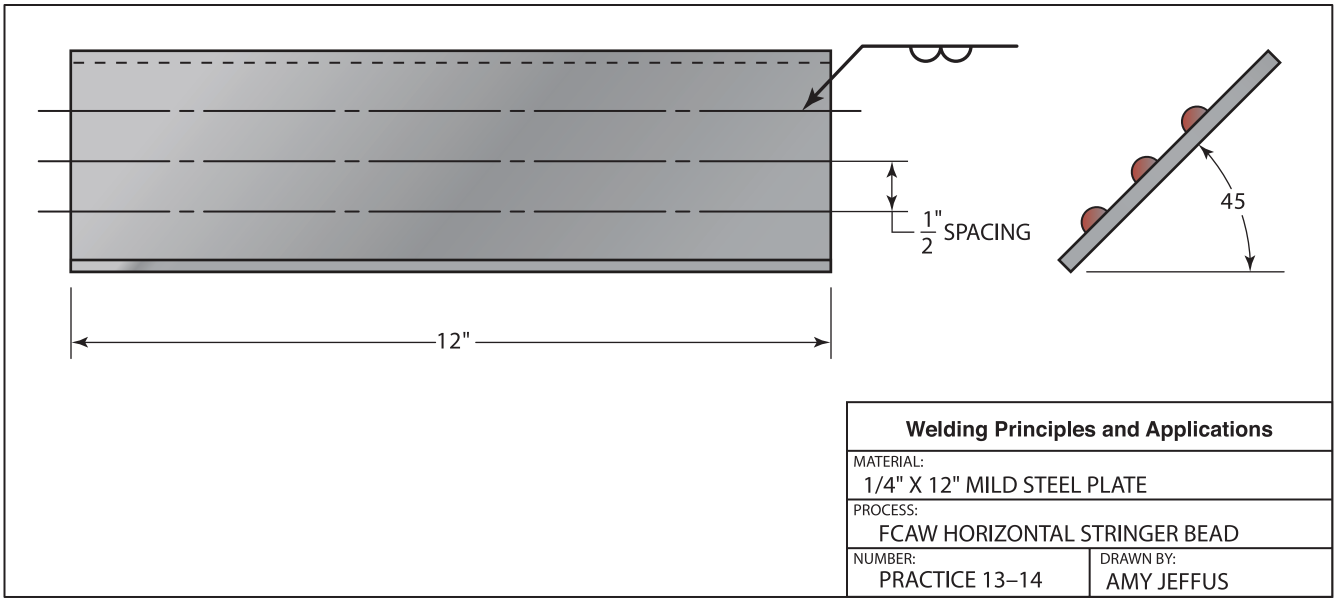


FIGURE 13-45 FCAW horizontal stringer bead.

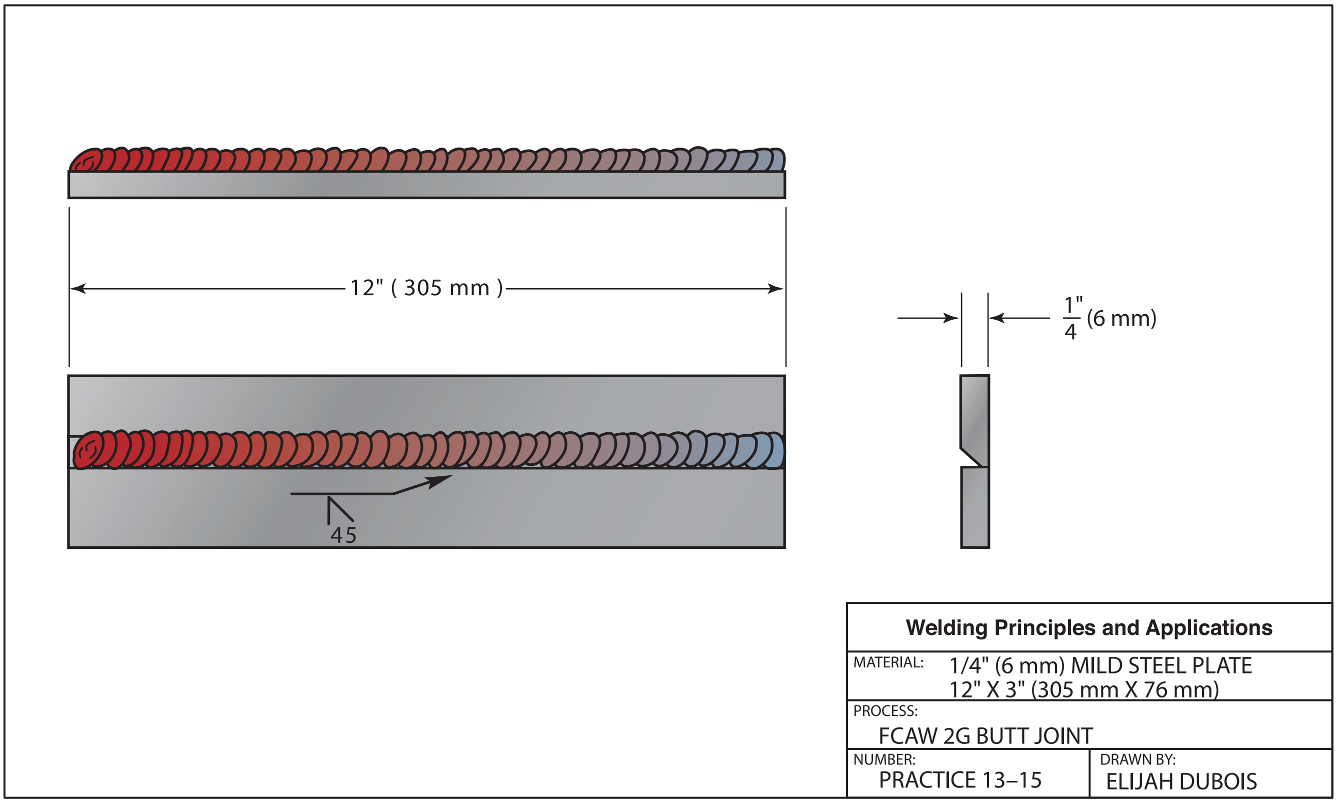


FIGURE 13-46 FCAW 2G butt joint, 1/4-in. (6-mm) mild steel.

beveled plates, two or more pieces of mild steel plate 7 in. (178-mm) long and 3/4-in. (19-mm)-thick beveled plates, and a 14-in.-long and a 9-in. (355-mm and 230-mm) -long, 1-in. (25-mm)-wide, and 1/4-in.(6-mm)-thick backing strip, you will make a groove weld in the horizontal position.

Following the same instructions for the assembly and welding procedure outlined in Practice 13-14, repeat with both classifications of electrodes as needed until defect-free welds can be consistently made. Turn off the welding machine and shielding gas and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

OVERHEAD-POSITION WELDS

PRACTICE 13-17

Square Butt Joint 4G

Using a properly set up and adjusted FCA welding machine, proper safety protection, 0.035-in. and/or 0.045-in. (0.9-mm and/or 1.2-mm) diameter E70T-1 and/or E70T-5 electrodes, and one or more pieces of mild steel plate 12 in. (305 mm) long and 1/4 in. (6 mm) thick or thinner, you will make a groove weld in the overhead position.

The molten weld pool should be kept as small as possible for easier control. A small molten weld pool can be achieved by using lower current settings and faster traveling speeds.

Lower current settings require closer control of gun manipulation to ensure that the electrode is fed into the molten weld pool just behind the leading edge. The low power will cause cold lap and more spatter if this electrode-to-molten weld pool contact position is not closely maintained.

Faster travel speeds allow the welder to maintain a high production rate even if multiple passes are required to complete the weld. Weld penetration into the base metal at the start of the bead can be obtained by using a slow start or quickly reversing the weld direction. Both the slow start and reversal of weld direction put more heat into the weld start to increase penetration. The higher speed also reduces the amount of weld distortion by reducing the amount of time that heat is applied to a joint.

When welding overhead, extra personal protection is required to reduce the danger of burns. Leather sleeves or leather jackets should be worn.

Much of the spatter created during overhead welding falls into or on the nozzle and contact tube. The contact tube may short-out to the gas nozzle. The shorted gas nozzle may arc to the work, causing damage to the nozzle and to the plate. To control the amount of spatter, a longer stickout and/or a sharper gun-to-plate angle is required to allow most of the spatter to fall clear of the gun or nozzle, **Figure 13-47**.

Make several short weld beads using various techniques to establish the method that is most successful and most comfortable for you. After each weld, stop and evaluate it before making a change. When you have decided on the technique to be used, make a welded stringer bead that is 12 in. (305 mm) long.

Repeat with both classifications of electrodes as needed until defect-free welds can be consistently made in the 1/4-in. (6-mm)-thick plate. Turn off the welding machine and shielding gas and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

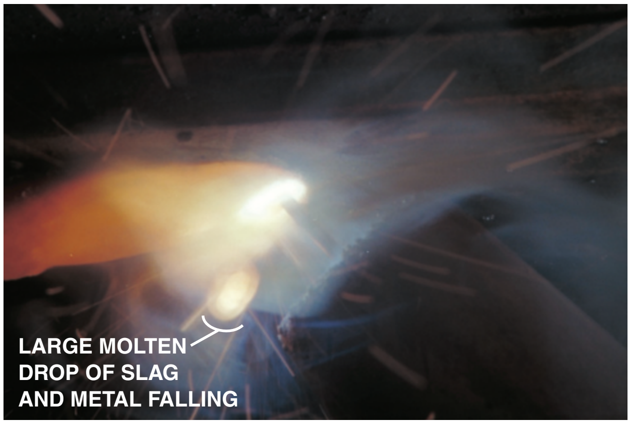


FIGURE 13-47 Hold the gun so that weld spatter will not fall onto the gun.

PRACTICE 13-18

V-Groove Butt Joint 4G

Using a properly set up and adjusted FCA welding machine, proper safety protection, 0.035-in. and/or 0.045-in. (0.9-mm and/or 1.2-mm) diameter E70T-1 and/or E70T-5 electrodes, two or more pieces of mild steel plate 12 in. (305 mm) long and 3/8-in. (9.5 mm)-thick beveled plate, two or more pieces of mild steel plate 7 in. (178-mm) long and 3/4-in. (19-mm)-thick beveled plate, and a 14-in.-long and a 9-in. (355-mm and 230-mm)-long, 1-in. (25-mm)-wide, and 1/4-in. (6-mm)-thick backing strip, you will make a groove weld in the overhead position, **Figure 13-48**.

Following the same instructions for the assembly and welding procedure outlined in Practice 13-17, repeat with both classifications of electrodes as needed until defect-free welds can be consistently made. Turn off the welding machine and shielding gas and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 13-19

Lap Joint and Tee Joint 4F

Using a properly set up and adjusted FCA welding machine, proper safety protection, 0.035-in. and/or 0.045-in. (0.9-mm and/or 1.2-mm) diameter E70T-1 and/or E70T-5 electrodes, two or more pieces of mild steel plate 12 in. (305 mm) long and 3/8-in. (9.5-mm)-thick beveled, and two or more pieces of mild steel plate 7 in. (178 mm) long and 3/4-in. (19-mm)-thick beveled plates, you will make a fillet weld in the overhead position, **Figure 13-49A** and **B**.

Following the same instructions for the assembly and welding procedure outlined in Practice 13-17, repeat each type of joint with both classifications of electrodes as needed until defect-free welds can be consistently made. Turn off the welding machine and shielding gas and clean your work area when you are finished welding.

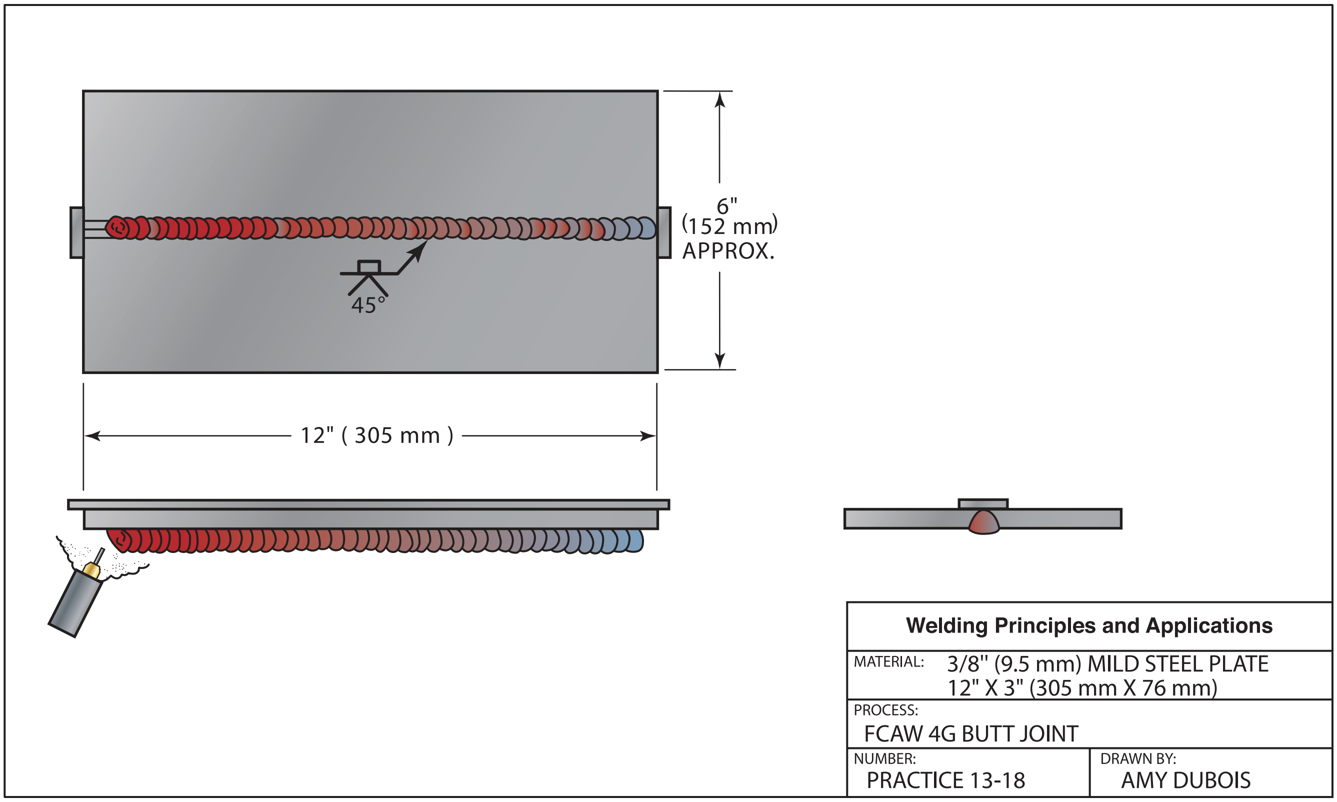


FIGURE 13-48 FCAW 4G butt joint, 3/8-in. (9.5-mm) mild steel.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

THIN-GAUGE WELDING

The introduction of small electrode diameters has allowed FCA welding to be used on thin sheet metal. Usually these welds will be a fillet type. Fillet welds are the easiest weld to make on thin stock. An effort should be made when possible to design the weld so it is not a butt-type joint. A common use for FCA welding on thin stock is to join it to a thicker member, **Figure 13-50**. This type of weld is used to put panels in frames.

The following practices include some butt-type joints. You will find that the vertical down welds are the easiest ones to make. If it is possible to position the weldment, production speeds can be increased if butt joints are required.

PRACTICE 13-20

Butt Joint 1G

Using a properly set up and adjusted FCA welding machine, **Table 13-2**, proper safety protection, 0.030-in. and/or 0.035-in. (0.8-mm and/or 0.9-mm) diameter E70T-1 and/or E70T-5 electrodes, and one or more pieces of mild steel sheet 12 in. (305 mm) long and 16 gauge to 18 gauge thick, you will make a butt weld in the flat position, **Figure 13-51**.

Do not leave a root opening for these welds. Even the slightest opening will result in a burnthrough. If a burnthrough occurs, then the welder can be pulsed off and on so that the hole can be filled. This process will leave a larger-than-usual buildup. Excessive buildup can be ground off if necessary as part of the postweld cleanup.

Repeat with both classifications of electrodes as needed until defect-free welds can be consistently made. Turn off the welding machine and shielding gas and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

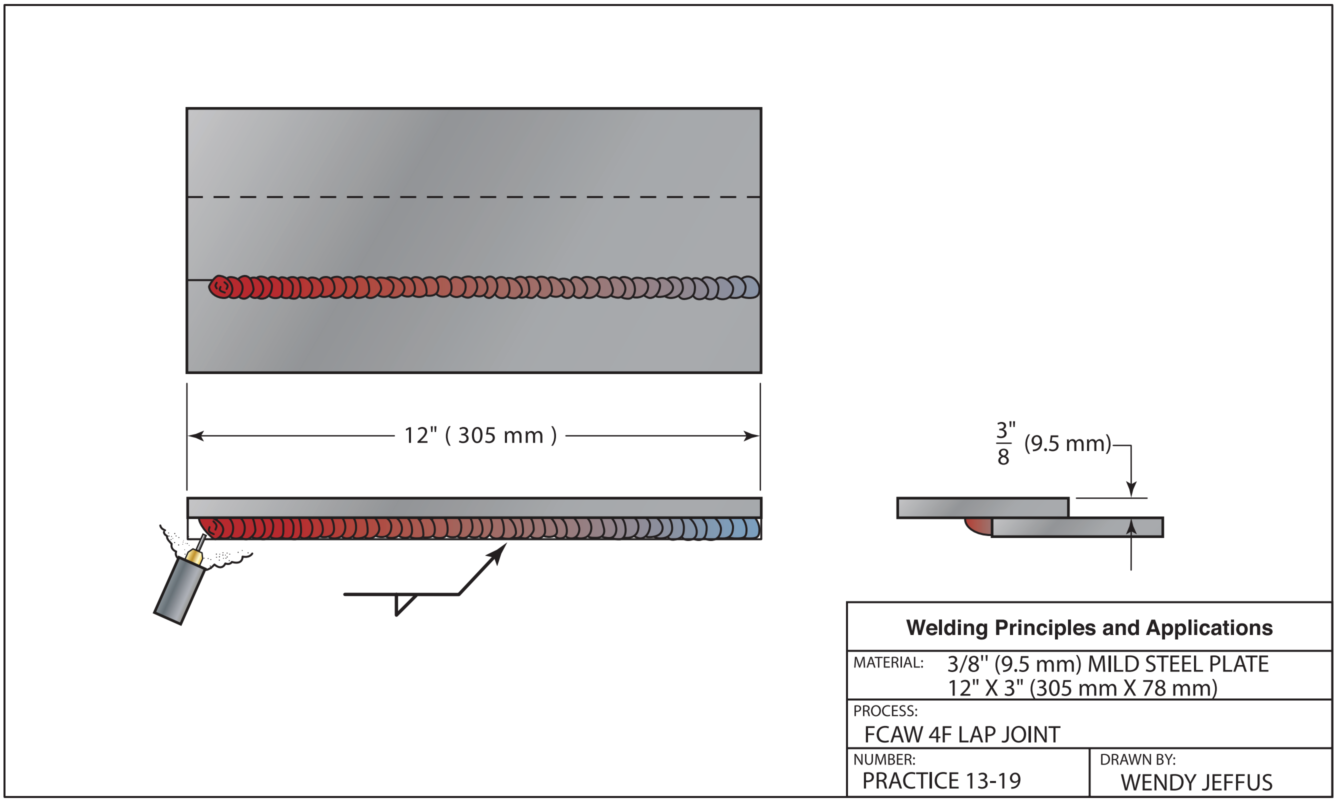
PRACTICE 13-21

Lap Joint and Tee Joint 1F

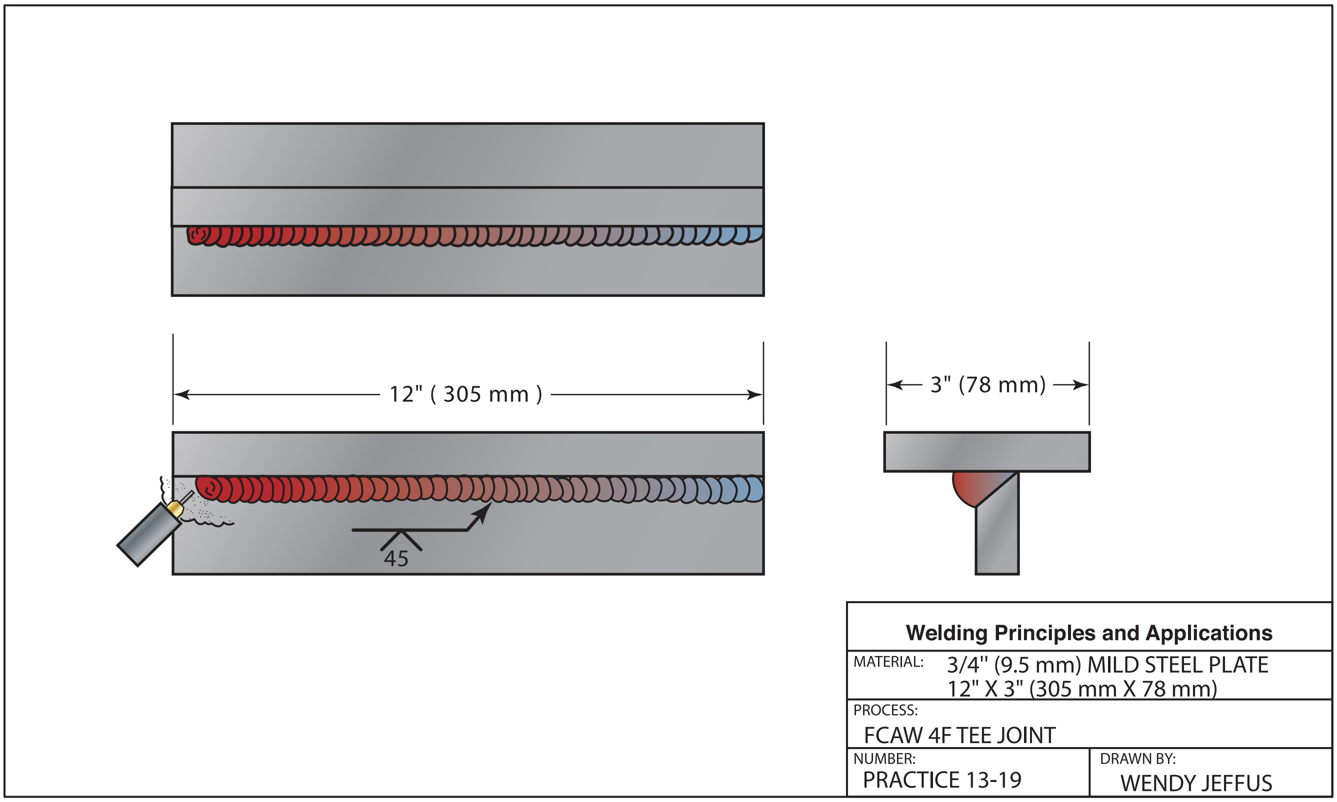
Using a properly set up and adjusted FCA welding machine, proper safety protection, 0.030-in. and/or 0.035-in. (0.8-mm and/or 0.9-mm) diameter E70T-1 and/or E70T-5 electrodes, and one or more pieces of mild steel sheet 12 in. (305 mm) long and 16 gauge to 18 gauge thick, you will make a fillet weld in the flat position.

Following the same instructions for the assembly and welding procedure outlined in Practice 13-20, repeat each type of joint with both classifications of electrodes as needed until defect-free welds can be consistently made. Turn off the welding machine and shielding gas and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆



(A)



(B)

FIGURE 13-49 (A) FCAW 4F lap joint, 3/8-in. (9.5-mm) mild steel. (B) FCAW 4F tee joint, 3/4-in. (9.5-mm) mild steel.

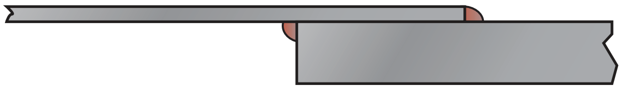


FIGURE 13-50 FCA welding thin to thick metal.

PRACTICE 13-22

Butt Joint 3G

Using a properly set up and adjusted FCA welding machine, proper safety protection, 0.030-in. and/or 0.035-in. (0.8-mm and/or 0.9-mm) diameter E70T-1 and/or E70T-5 electrodes, and one or more pieces of mild steel sheet 12 in. (305 mm) long and 16 gauge to 18 gauge thick, you will make a butt weld in the vertical up or down position.

Following the same instructions for the assembly and welding procedure outlined in Practice 13-20, repeat with both classifications of electrodes as needed until defect-free welds can be consistently made. Turn off the welding machine and shielding gas and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 13-23

Lap Joint and Tee Joint 3F

Using a properly set up and adjusted FCA welding machine, proper safety protection, 0.030-in. and/or

Electrode		Welding Power			Shielding Gas		Base Metal	
Type	Size	Amps	Wire-Feed Speed IPM (cm/min)	Volts	Type	Flow	Type	Thickness
E70T-1	0.030 in. (0.8 mm)	40 to 145	90 to 340 (228 to 864)	20 to 27	None	n/a	Low carbon steel	16 gauge to 18 gauge
E70T-1	0.035 in. (0.9 mm)	130 to 200	288 to 576 (732 to 1463)	20 to 28	None	n/a	Low carbon steel	16 gauge to 18 gauge
E70T-5	0.035 in. (0.9 mm)	90 to 200	190 to 576 (483 to 1463)	16 to 29	75% argon 25% CO_2	35 cfh	Low carbon steel	16 gauge to 18 gauge

TABLE 13-2 FCA Welding Parameters for Use if Specific Settings Are Unavailable from Electrode Manufacturer

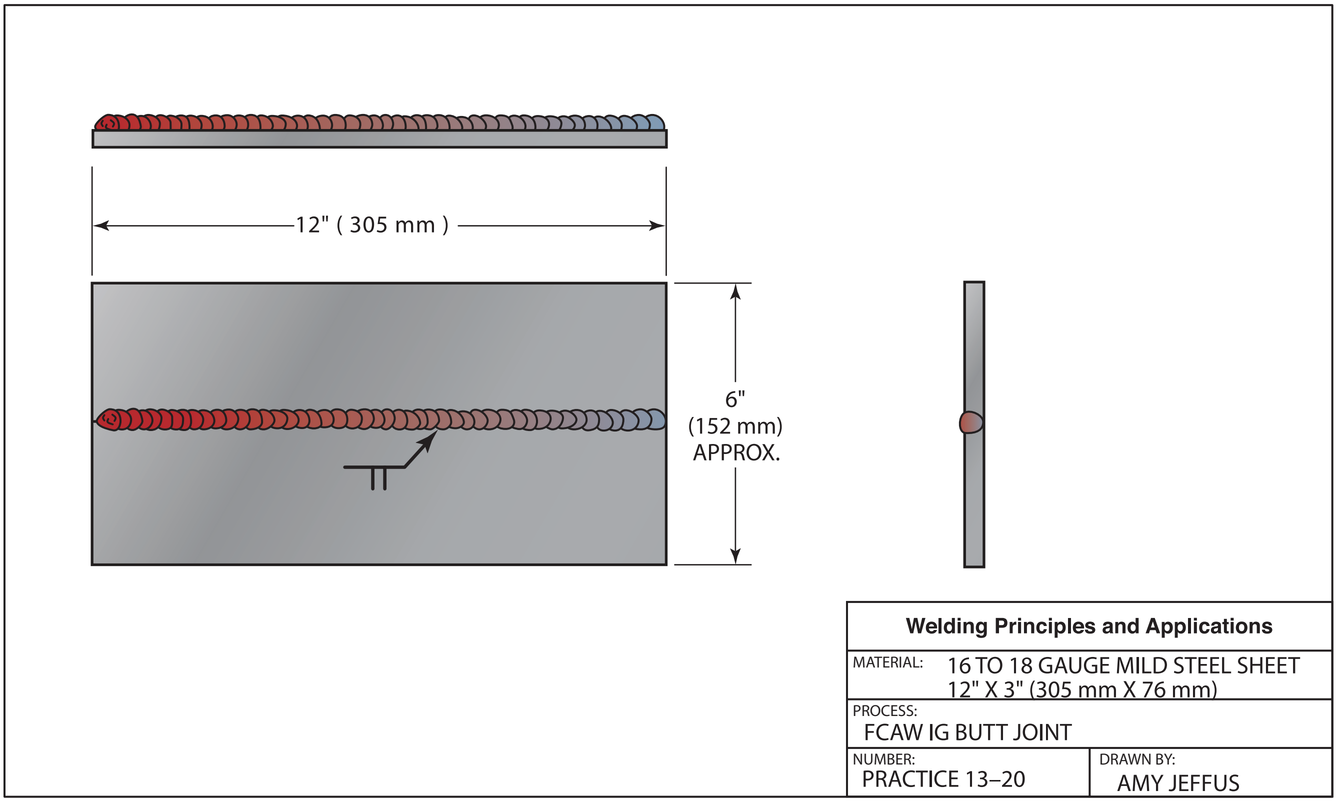


FIGURE 13-51 FCAW 1G butt joint, 16- to 18-gauge mild steel.

0.035-in. (0.8-mm and/or 0.9-mm) diameter E70T-1 and/or E70T-5 electrodes, and one or more pieces of mild steel sheet 12 in. (305 mm) long and 16 gauge to 18 gauge thick, you will make a fillet weld in the vertical up or down position.

Following the same instructions for the assembly and welding procedure outlined in Practice 13-20, repeat each type of joint with both classifications of electrodes as needed until defect-free welds can be consistently made. Turn off the welding machine and shielding gas and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 13-24

Lap Joint and Tee Joint 2F

Using a properly set up and adjusted FCA welding machine, proper safety protection, 0.030-in. and/or 0.035-in. (0.8-mm and/or 0.9-mm) diameter E70T-1 and/or E70T-5 electrodes, and one or more pieces of mild steel sheet 12 in. (305 mm) long and 16 gauge to 18 gauge thick, you will make a fillet weld in the horizontal position.

Following the same instructions for the assembly and welding procedure outlined in Practice 13-20, repeat each type of joint with both classifications of electrodes as needed until defect-free welds can be consistently made. Turn off the welding machine and shielding gas and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 13-25

Butt Joint 2G

Using a properly set up and adjusted FCA welding machine, proper safety protection, 0.030-in. and/or 0.035-in. (0.8-mm and/or 0.9-mm) diameter E70T-1 and/or E70T-5 electrodes, and one or more pieces of mild steel sheet 12 in. (305 mm) long and 16 gauge to 18 gauge thick, you will make a butt weld in the horizontal position.

Following the same instructions for the assembly and welding procedure outlined in Practice 13-20, repeat with both classifications of electrodes as needed until defect-free welds can be consistently made. Turn off the welding machine and shielding gas and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 13-26

Butt Joint 4G

Using a properly set up and adjusted FCA welding machine, proper safety protection, 0.030-in. and/or 0.035-in. (0.8-mm and/or 0.9-mm) diameter E70T-1 and/or E70T-5 electrodes, and one or more pieces of mild steel sheet 12 in. (305 mm) long and 16 gauge to 18 gauge thick, you will make a butt weld in the overhead position.

Following the same instructions for the assembly and welding procedure outlined in Practice 13-20, repeat with both classifications of electrodes as needed until defect-free welds can be consistently made. Turn off the welding machine and shielding gas and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 13-27

Lap Joint and Tee Joint 4F

Using a properly set up and adjusted FCA welding machine, proper safety protection, 0.030-in. and/or 0.035-in. (0.8-mm and/or 0.9-mm) diameter E70T-1 and/or E70T-5 electrodes, and one or more pieces of mild steel sheet 12 in. (305 mm) long and 16 gauge to 18 gauge thick, you will make a fillet weld in the overhead position.

Following the same instructions for the assembly and welding procedure outlined in Practice 13-20, repeat each type of joint with both classifications of electrodes as needed until defect-free welds can be consistently made. Turn off the welding machine and shielding gas and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PLUG WELDS

Plug welds are made by cutting or drilling a hole through the top plate and making a weld through that hole onto the plate that is directly behind the top plate, **Figure 13-52**. They are also used to join a thin section to another thin section or a thin section to a thicker section, **Figure 13-53**. Welding on a thin section's edge often causes that edge to melt away due to overheating of the thin edge, **Figure 13-54**. Sometimes plug welds are used to make blind welds that would not show after the weldment is finished.

PRACTICE 13-28

Plug Weld

Using a properly set up and adjusted FCA welding machine, proper safety protection, 0.030-in. and/or 0.035-in. (0.8-mm and/or 0.9-mm) diameter E70T-1 and/or E70T-5 electrodes, and two pieces of mild steel plate that are 1/4 in. (6 mm) thick, you will make a plug weld in the flat position.

Using an OFC or PAC torch and proper safety protection, lay out and cut a 1-in. (25-mm) diameter hole through the top plate. Clean any slag off the back side of the cut, grinding it smooth if necessary so that the top plate will sit

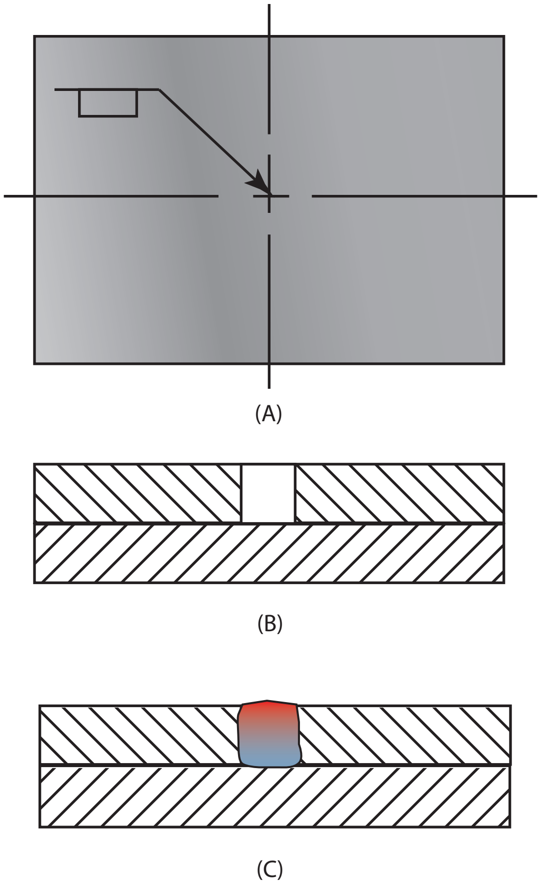


FIGURE 13-52 Plug weld.

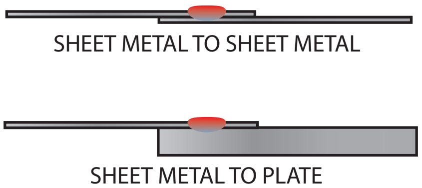


FIGURE 13-53 Plug welds can be used to join sheet metal to sheet metal or sheet metal to plate.

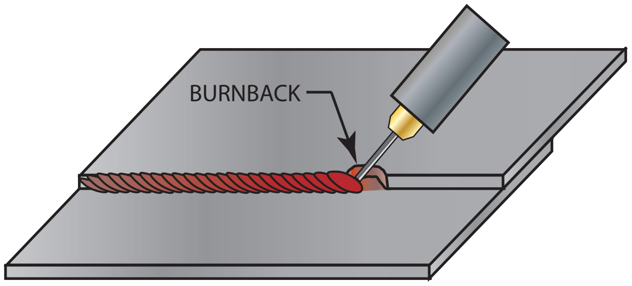


FIGURE 13-54 Welding too slowly or not having the correct gun angle can result in the thin edge burning back on lap joints.

flat on the bottom plate. Clamp the plates together using a C-clamp, **Figure 13-55**.

NOTE

On thicker metal the plug weld sides are typically beveled to make it easier to join the circumference of the plug plate to the base plate.

Be sure you have full range of movement so that you can keep the welding gun pointed at the root of the weld at approximately a 45° angle. Start the weld at the bottom edge of the hole, **Figure 13-56**, and make a full circumference of the plug weld joint. Pull the trigger and make the weld. Try to make the weld all the way around the bottom edge of the hole, but if you cannot, then stop and chip the weld before starting the next weld. Once the weld has been completed all the way around the base, stop and chip the slag. If you do not chip the slag out of a deep plug weld, then the slag

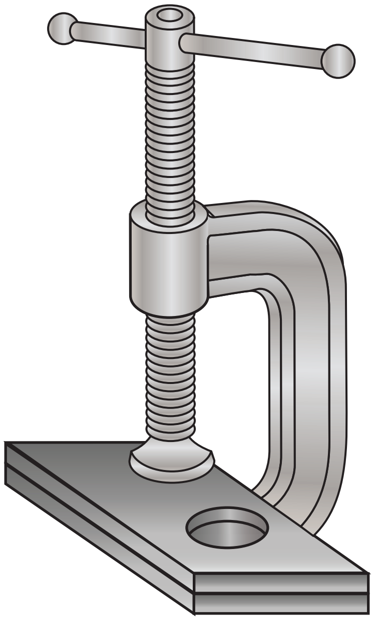


FIGURE 13-55 Clamping the plates together before making the plug weld will prevent gapping between the plates.

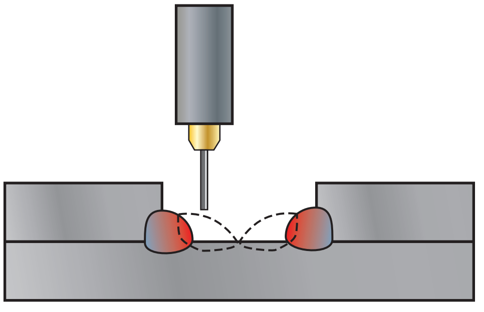


FIGURE 13-56 Start the plug weld around the bottom edge of the hole.

can build up excessively, making it impossible for you to maintain visibility of the weld and prevent slag inclusions.

The next weld pass will be mainly on the base plate, lapping halfway up on the previous weld, **Figure 13-57**. Hold the welding gun perpendicular to the plate and make the weld all the way around. Continue the circular pattern, expanding it all the way out to the outside, and make two complete passes. Stop and chip the slag. Finish the weld by starting in the center, and build it up until the weld bead is flush with the surface.

Turn off the welding machine and shielding gas, and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

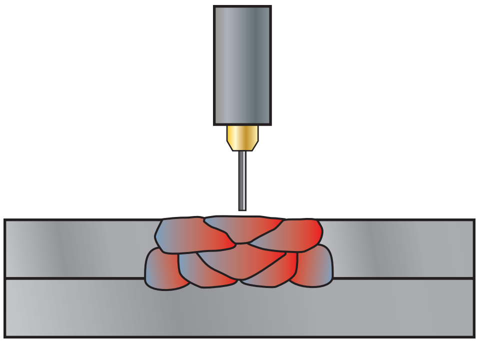


FIGURE 13-57 Complete the plug weld by making the necessary passes. It may be necessary to stop, chip, and clean the slag when making plug welds on thick metal sections.

Summary

In semiautomatic welding processes, the weld travel rate along the joint is controlled more by the process than by your welding technique. You must therefore learn how to travel at the proper rate to maintain the weld size. Flux cored arc welding is a relatively fast process. Therefore, your travel rates are much higher than for most other welding processes. This often causes new welders problems in that they have difficulty maintaining joint tracking as they are rapidly traveling along the groove. Practicing movement along the joint before you start is a good way of aiding in your development of these skills. Many of the practice coupons in this section are 12 in. (305 mm) in length. However, if given the opportunity, you may want to weld longer joints after you have mastered the basic skills to further increase your joint tracking abilities.

Flux cored arc welding produces a large quantity of welding fumes. It is important that you position yourself so that your head is not directly in line with the rising fumes. Make sure you are welding so that your face is well out of this rising plume of welding fumes. In the field, welders sometimes use fans to gently blow the fumes away from them. However, if the fan is too close to the welding zone, excessive air velocity will blow the shielding away from the weld, which may result in weld porosity. Take precautions to protect yourself from any potential health hazards.

Review

1. Why is it important to make sure that an FCA welding system is set up properly if out-of-position welds are going to be made?
2. What major safety concerns should an FCA welder be cautious of?
3. Why should the FCA welding practice plates be large?
4. Why should the FCA welds be of substantial length?
5. What must be done to a shielding gas cylinder before its cap is removed?
6. What can happen to the wire if the conduit is misaligned at the feed rollers?
7. Why is it a good idea for a new student welder to use the gas nozzle even if a shielding gas is not used?
8. Why is the curl in the wire end straightened out?
9. What problems can a high-feed roller pressure cause?
10. Referring to Table 13-1, answer the following:
    a. What would the range of the feed speed be for an amperage of 150 at 25 volts for an E70T-1 0.035-in. (0.9-mm) electrode?
    b. What would the approximate amperage be for an E70T-5 0.045-in. (1.2-mm) electrode if it is being fed at a rate of 200 in. per minute (508 cm per minute)?
11. What are the disadvantages of beveling plates for welding?
12. What is the maximum plate thickness that an FCS weld can be made with 100% penetration without beveling the joint?

13. What is the smallest V-groove angle that can be welded using the FCA welding process?
14. What is the purpose of the root pass?
15. Why is the FCA welding process not used for open-root critical welds?
16. Why should convex weld faces be avoided?
17. What bead pattern is best for overhead welds?
18. Why is the appearance of the cover pass so important?
19. What are the visual inspection standard's limitations of acceptance?
20. Why is the backing strip 2 in. (50 mm) longer than the test plate?
21. Why should there be a space between the plates when making a fillet weld on thick plates of a tee joint?
22. What would a small notch at the root weld's leading edge in a fillet weld mean?
23. What changes should be made in the setup for making a vertical up weld?
24. What problem must be overcome if the amperage and voltage are lowered to make a vertical weld?
25. How can higher welding speeds help control distortion?
26. How can spatter buildup on the welding gun be controlled in the overhead position?

Chapter 14

Gas Metal Arc and Flux Cored Arc Welding of Pipe

OBJECTIVES

After completing this chapter, the student should be able to

- demonstrate the ability to make root pass welds using GMAW, FCAW-G, and FCAW-S processes.
- demonstrate the ability to make hot pass welds using GMAW, FCAW-G, and FCAW-S processes.
- demonstrate the ability to make filler pass welds using GMAW, FCAW-G, and FCAW-S processes.
- demonstrate the ability to make cover pass welds using GMAW, FCAW-G, and FCAW-S processes.
- demonstrate how to grind a tack weld and weld starts and stops to a featheredge.
- explain the acceptable criteria of a visual inspection of a pipe weld.

KEY TERMS

cover pass(es)
end preparation
filler pass
hot pass
joint cleaning
joint fitup
joint preparation
root pass
tack welds
visual inspection

INTRODUCTION

Both GMA and FCA pipe welding processes are combined in this chapter because in the field they are often used together to make pipe welds. Some FCAW electrodes have fast freeze fluxes that allow larger weld beads to be made in all positions. That makes FCA welding ideal for rapidly filling a grooved pipe joint. However, FCA welding does not work as well as GMA welding for **root passes**. Unless a backing ring is used, most root passes are made with the GMA process. The remainder of the groove can be welded out with the GMA process, or it may be finished with the FCA process because it is faster. To make it easier to change from GMA to FCA welding, a number of manufacturers have welding machines that have two wire feeders, one for GMA and the other for FCA.

Before beginning the pipe welds in this chapter, you should have completed many of the GMA and FCA welding practices in Chapters 11 and 13.

JOINT PREPARATION

The shaping, cleaning, fitting, and tack welding of pipe joints are critical steps required to make a code quality weld. Do not try to rush through these steps; take your time and do them correctly.

End Preparation

The ends of pipe are beveled to between 30° and 35° to form a 60° to 70° V-groove when they are put together, **Figure 14-1**. A small flat surface 1/16 in. (1.6 mm) wide, called the root face or land, is ground or machined on the beveled edge. Once the root face is ground, place the pipe on a smooth flat surface to see if it is flat. Mark any areas that show a gap larger than 1/16 in. (1.6 mm) so that the adjacent high area can be ground or filed off. Repeat this process until the pipe end is even.

Preassembly Joint Cleaning Once the root face has been prepared, the inside and outside pipe surfaces must be ground clean back 1 in. (25 mm) from the joint. This **joint cleaning** is required to prevent surface contamination from causing weld defects.

CAUTION

When grinding, be very careful not to gouge the surface of the pipe, groove face, or root face. Deep gouges in these surfaces can be considered defects.

Joint Fitup

Pipe is not always round; in fact, large diameter pipe is almost always not round. There are welding gages, called high-low gages, that are specifically designed to check for the alignment of pipe, **Figure 14-2**. According to the API code, for pipes of the same nominal diameter the offset must not be more than 1/8 in. (3 mm). One way to minimize the offset is to line up the seam in welded pipe. Although the welded seam is machined smooth, it is usually easy to find by looking at the inside surface of the pipe.

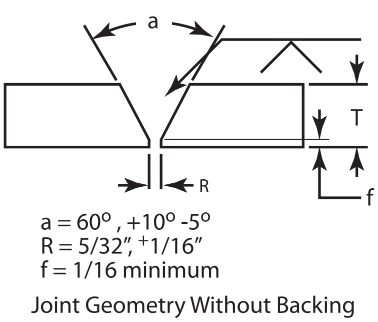


FIGURE 14-1 Standard pipe V-groove specifications.

FIGURE 14-2 High-low gage.

NOTE

Use a pair of pliers to catch the pipe coupons as they are being cut off so they do not drop to the floor. Falling to the floor can cause the hot pipe coupon to bend, making it harder to fit up properly.

There are a number of tools specially designed to force pipe section into alignment. However, if one of these devices is not available, then there are several ways to adjust the pipe so it can be aligned properly. One way is to place the coupon on an anvil and strike it with a hammer. Another way is to tack the joint together where it is in alignment and use a clamp or dog and wedge to force the pipe into alignment, **Figure 14-3**.

Tack Welds

It is important that **tack welds** are made with the same welding procedure as the finish welds so that they do not become weld defects in the finished weld. The number and size of tack welds will vary depending on the pipe's diameter and wall thickness. Larger, thicker pipes will require more tack welds to keep the root opening from being changed due to welding stresses. The welding procedure for the pipe you are welding should have the number, size, and location of the required tack welds listed.

The ends of the tack welds must be ground to a featheredge so that the root weld can achieve 100% penetration at their ends. Grinding must be done with a thin grinding disk to ensure that metal on the sides of the groove is not removed as the tack welds are being feathered, **Figure 14-4**.

THINK GREEN

Although arc strikes outside of the weld groove or other potential defects happen as you are welding, do not discard a pipe welding test specimen before the joint is completed just because of a known defect in the weld. That wastes both your preparation time and the piping material. Complete the practice welds in the joint to save time and materials as you improve your techniques.

Root Pass

The root pass can be made uphill or downhill. It is easier to control the root penetration by making an uphill weld if the root opening is wider than normal. The uphill technique

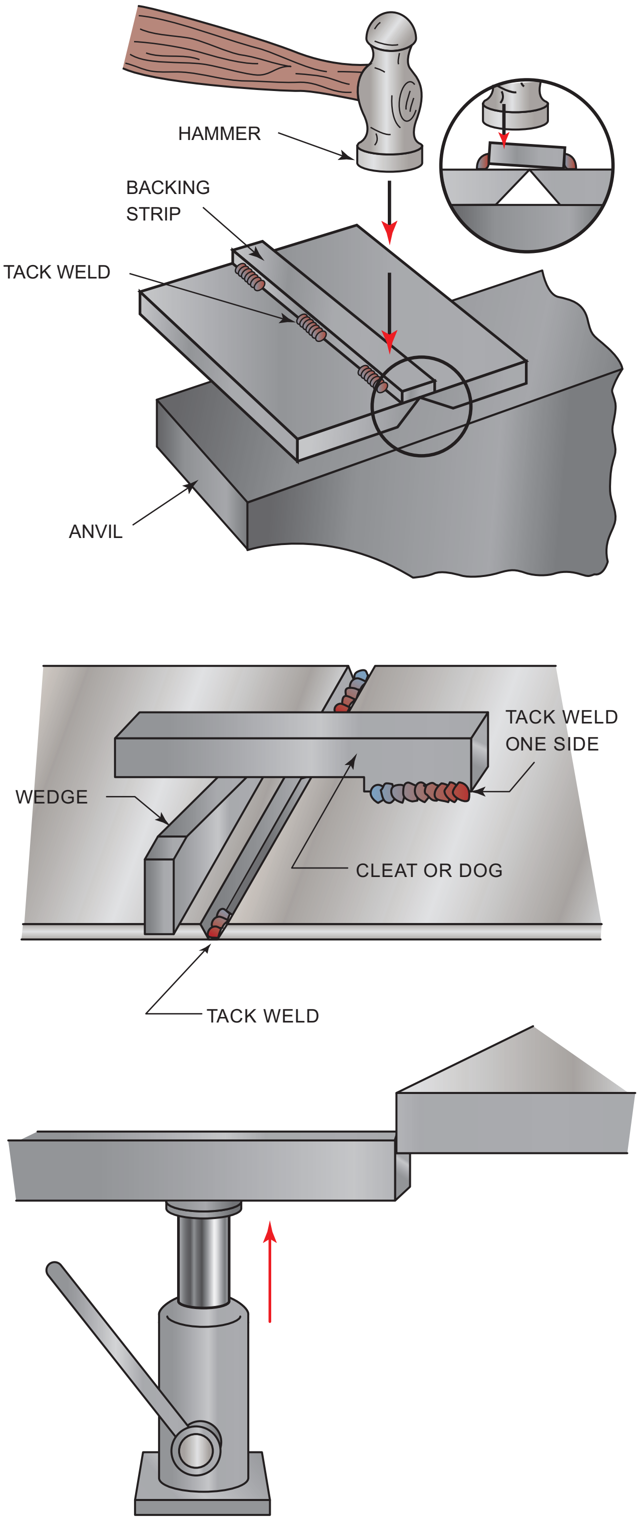


FIGURE 14-3 Techniques for aligning tack welds.

should also be used if the root opening is narrower than normal. It is faster, however, to make the root weld using the downhill technique if the root opening is uniform and not too wide or narrow. Both uphill and downhill welds should be practiced.

The root pass welds must start and end on the tack welds, because it is difficult to get 100% weld penetration the instant

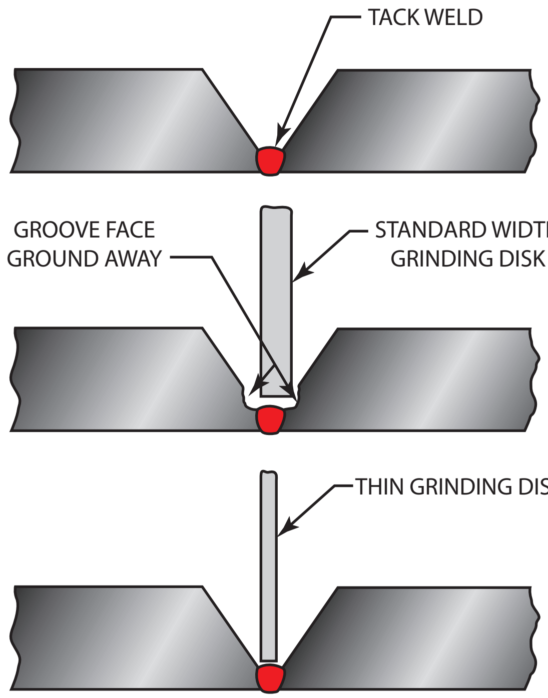


FIGURE 14-4 Using a narrow grinding disk avoids damaging the groove face.

that both GMA and FCA welds start. Starting the weld on top of the tack will eliminate the potential lack of fusion at the start of the weld. Once the root pass is completed, the root surface can be examined for 100% penetration, fusion, concavity, excessive reinforcement, and icicles.

The weld face can be cleaned using a chipping hammer, punch, and wire brush. Any areas of undercut that have trapped slag or areas with more than 1/16 in. (1.6 mm) buildup can be ground down using a grinder with a narrow grinding disk.

Hot Pass

The **hot pass** is used to reshape the face of the root weld, burn out any small pieces of trapped slag, and in some cases push the root penetration a little deeper if the root pass did not have 100% penetration all the way around the pipe.

The hot pass can be made with either the GMA or the FCA welding process. Both processes should be practiced so that you will be able to take the SENSE qualification test and so you will have the skills needed for many welding jobs.

The hot pass can be made uphill or downhill; however, it is more difficult to keep good fusion when using the downhill technique. For that reason, new welders often have more success when making the hot pass uphill. Both techniques should be practiced.

Filler Pass

The bulk of the weld metal added to a groove weld is made up of the **filler passes**. These weld passes are typically made in the uphill progression. They only need to have complete fusion to the previous weld and do not need to

have deep penetration. Keep the filler passes as uniform in width and reinforcement as possible. Stop making filler passes when the weld surface is approximately 1/16 to 1/8 in. (1.6 to 3 mm) below the pipe's outer surface so there will be room for the cover passes.

Cover Pass(es)

The **cover pass** or passes are sometimes called the cap. These are the final welds that complete the pipe weld. The visual appearance of the cover pass is often the only inspection that noncritical welds receive. It is also the only weld on any pipeline job that everyone sees and uses to judge your abilities as a welder. If you can make great cover passes, most welders know that you are probably making great root, hot, and filler passes too.

Visual Inspection

Visually inspect the weld for uniformity and discontinuities. There shall be no cracks, no incomplete fusion, and no overlap. Undercut shall not exceed the lesser of 10% of the base metal thickness or 1/32 in. (0.8 mm), and the weld must be free of overlap. The frequency of porosity shall not exceed one in each 4 in. (100 mm) of weld length, and the maximum diameter shall not exceed 3/32 in. (2.4 mm). The maximum reinforcement of the cover pass is 1/8 in. (3 mm), and it cannot be any wider than 1/8 in. wider than the groove being welded, **Figure 14-5**.

PRACTICE PIPE WELDS

Each of the practice welds should be made with GMAW, FCAW-S, and FCAW-G welding processes. You will need the following items for each of the practice welds: wire cutters or MIG pliers, channel lock-type pliers, a grinder, wire brush, chipping hammer, punch, and all the required PPE. The welds are to be made using the following filler metals and shielding gasses:

- GMA welds will be made using 0.035 diameter ER70-S filler metal with 75% Ar + 25% CO_2 or Ar + 2% to 5% O_2 shielding gas.

FIGURE 14-6 Plastic sheeting to protect glass from weld spatter.

- Self-shielded FCA welds will be made with 0.035 or 0.045 diameter E71T-11.
- Gas-shielded FCA welds will be made with 0.035 or 0.045 diameter with 75% Ar + 25% CO_2 shielding gas.

PIPE TO PLATE WELDS

Pipe sockets are joined to pipe with fillet welds. Pipe sockets are used in power plants, chemical plants, industrial hydraulics, and architectural applications such as handrails. Pipe may also be joined to plate to make it easier to attach the pipe to the wall or floor for a handrail, equipment base, or it may be used to close off the end of a pipe, **Figure 14-6**. To make this type of a joint, a fillet weld is used. The end of the pipe may be beveled to form a groove, or the fillet weld can be made without a beveled pipe end. The technique is similar for both types of joints.

PRACTICE 14-1

Fillet Weld, 1F Position, Using GMAW, FCAW-S, and FCAW-G

Using a properly set up and adjusted CP welding machine, proper safety protection, welding electrodes, and one piece of schedule 40 mild steel pipe 3 in. to 6 in. (76 to 150 mm)

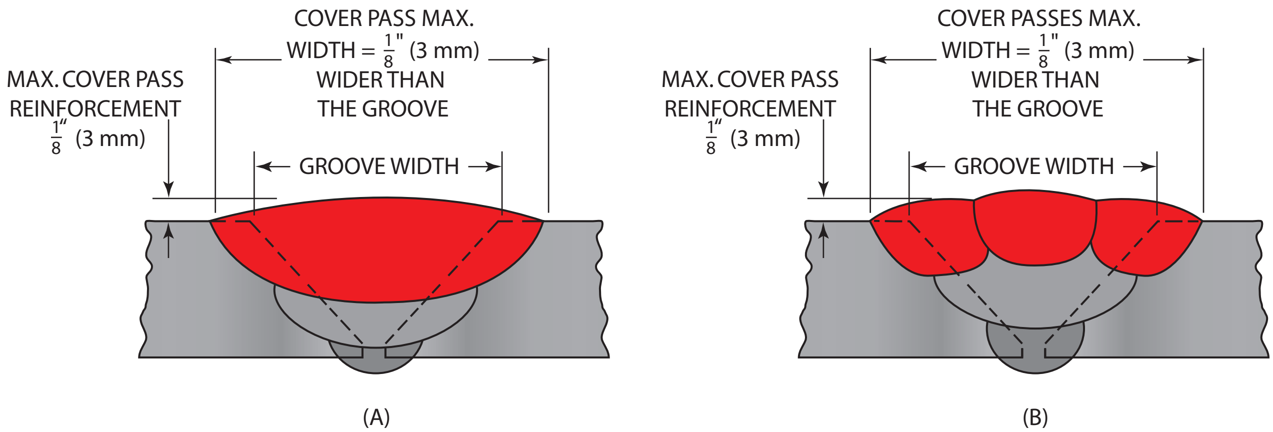


FIGURE 14-5 Maximum weld size for a single and multiple cover pass.

in diameter, and a 4-in. or 7-in. (100-mm or 170-mm) 1/4-in. (6 mm) mild steel plate, you will make a pipe-to-plate fillet welded joint in the 1F flat rolled position using each of the three wire welding processes, **Figure 14-7**.

Mark a straight line around the pipe using a pipe wrap-around or other pipe layout tool. Using all of the appropriate PPE for a flame cutting torch or plasma cutting torch and following all of the equipment manufacturer's safety and operating guidelines, make a cut along the line, **Figure 14-8**. Clean any slag off, and grind the end if necessary to have the pipe stand vertically on the plate.

Tack weld the plate to the pipe with four equally spaced approximately 1-in. (25-mm)-long welds. Grind the ends of the weld to a featheredge using a thin disk-grinding wheel.

The welds on this practice will have three passes. The first pass will be made with the short-circuiting metal transfer process, and the last two passes will be made using the spray metal transfer process.

Mount the pipe and plate at a 45° angle so that it can be turned between welds and so that the surface of the fillet weld will remain in the flat position. Position the pipe so that the tack welds are at approximately the 1:30 o'clock and 10:30 o'clock positions. Start the first weld on the 1:30 o'clock position, and weld toward the 10:30 o'clock position. The gun should be a slight forehand angle; transition to a perpendicular angle at approximately the 12:00 o'clock position, then onto a slight backhand position as it moves toward the 10:30 o'clock position. The weld bead should be approximately 3/16 in. (4.8 mm), **Figure 14-9**.

Visually inspect the root surface to see if you have complete fusion and no overlap. Discuss with your instructor what you need to do to improve your root weld. Rotate the pipe so you can make the next root weld. Make the necessary changes in the machine settings before starting the next weld. Repeat this process until you have made the root pass all the way around the pipe. Chip and wire brush the root, and grind any areas that need additional cleanup.

The next two weld passes will be made using the spray metal transfer method. Using the same gun angle as you used for the root pass, make a filler pass over the root weld. Use a slight weaving pattern to make the weld bead wide enough to cover the root weld. To reduce the need for grinding, speed up your travel rate slightly just before stopping the weld. This will result in a slight tapering down of the weld bead and can eliminate the need to grind the end of the weld. However, you should grind the starting point of this first weld so that when you get all the way around, you can tie the ending of the weld smoothly into the starting point of the weld pass.

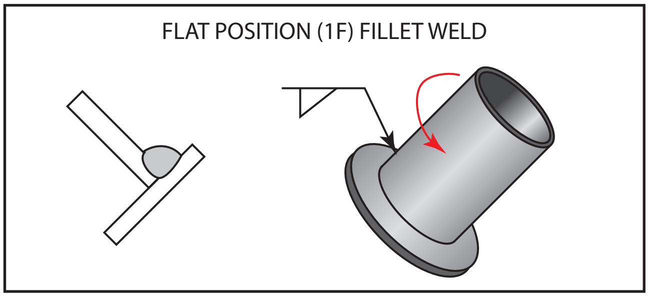


FIGURE 14-7 1F weld position.

FIGURE 14-8 Use a guide to make an accurate plasma cut.

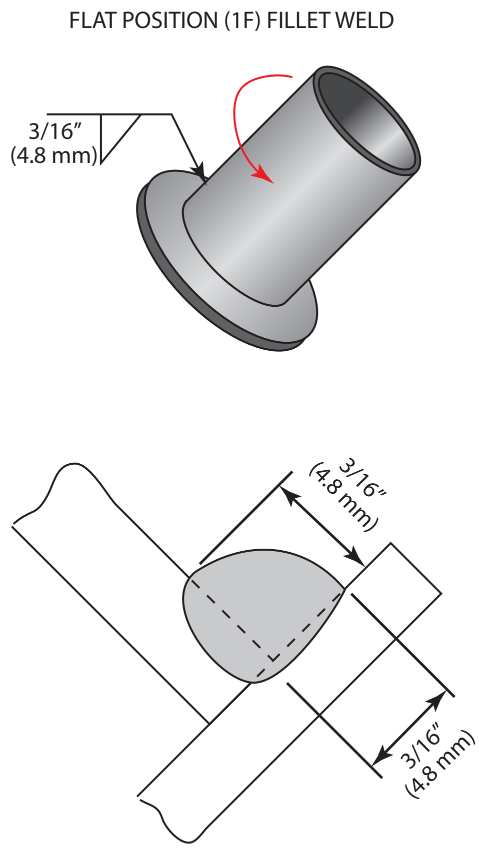


FIGURE 14-9 Fillet weld leg size.

Visually inspect the root surface to see if you have complete fusion and no overlap. Discuss with your instructor what you need to do to improve your root weld. Rotate the pipe so you can make the next root weld. Make the necessary changes in the machine settings before starting the next weld. Repeat this process until you have made the filler pass all the way around the pipe. Chip and wire brush the root, and grind any areas that need additional cleanup.

The cover pass will be made with the same technique as the filler pass; however, a slightly wider weave pattern will be needed. Visually inspect the weld, and repeat this weld as needed with all three processes until you can consistently make welds free of defects. Turn off the welding machine and clean your work area when you are finished welding. Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 14-2

Fillet Weld, 2F Position, Using GMAW, FCAW-S, and FCAW-G

Using the same equipment and materials as practice 14-1, you are going to make a fillet weld in the 2F position using each of the three wire welding processes, **Figure 14-10**.

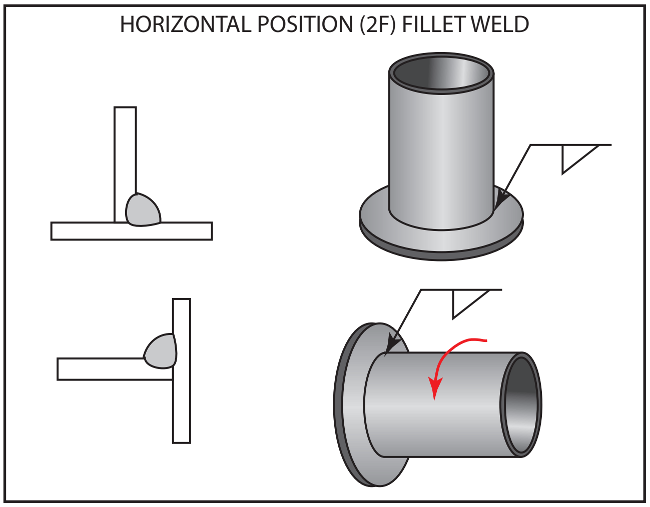


FIGURE 14-10 The two possible positions for a 2F horizontal fillet weld.

Using a 15° to 20° backhand gun angle and a 35° to 40° work angle, start the weld on one of the tack welds, and make a stringer weld all the way to the center of the next tack weld, **Figure 14-11**. As you get to the tack weld, speed up your travel rate to taper the size of the weld down to make it easier to restart the next weld bead. Chip and wire brush the weld, and visually inspect it for uniformity and any undercut or overlap. The weld bead should have equal legs of approximately 3/16 in. (4.8 mm). The weld should be equal on both the plate and side of the pipe.

CAUTION

Sometimes it is difficult to see the contact tube when making these fillet welds, especially if you try to make long welds without repositioning. If that happens while using the spray metal transfer and the tip gets too close to the weld, it can melt. When that happens, the tip is destroyed and the copper from the tip that might enter the weld pool will make a very brittle defect in the weld. Recessing the contact tube tip inside of the nozzle can help prevent this but might restrict your vision of the weld.

If there is undercut along the top toe of the weld or if the weld leg is not as large on the top side, you will need to decrease the work angle to direct more metal onto the pipe side. You may also want to make a slight J weave pattern to help correct this problem. Discuss with your instructor what you need to do to improve your root penetration before making the weld on the opposite side. Make any corrections to your technique and complete the weld all the way around the pipe.

The second weld pass will be made using the spray metal transfer method. This weld bead will be placed around the lower side of the first weld so that approximately two-thirds to three-quarters of the root weld face is covered by this weld pass, **Figure 14-12**. Chip and wire brush the weld each time you stop to reposition yourself. Visually inspect the weld, and discuss with your instructor what you need to do to improve your weld. Complete the weld all the way around the pipe.

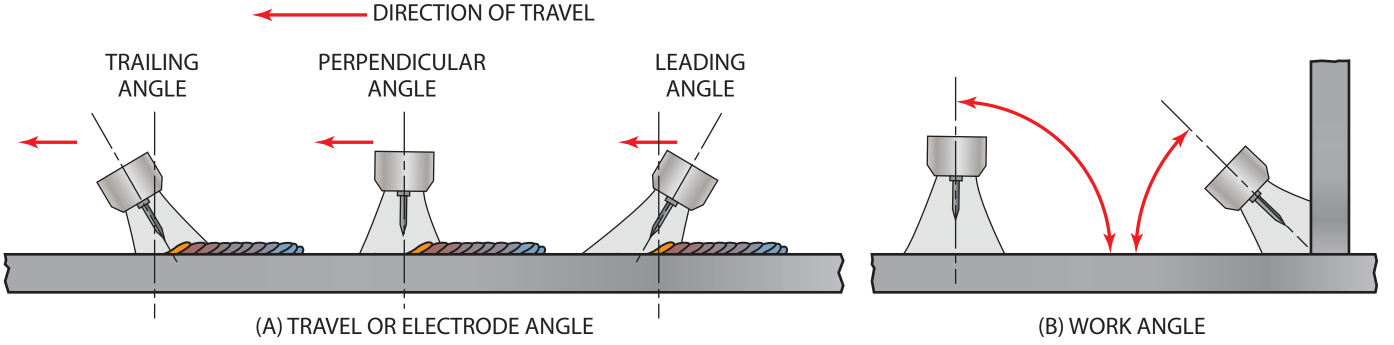


FIGURE 14-11 (A) Travel angle. (B) Work angle.

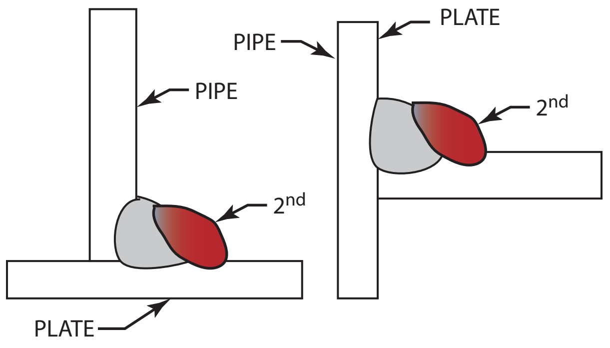


FIGURE 14-12 Second filler weld placement.

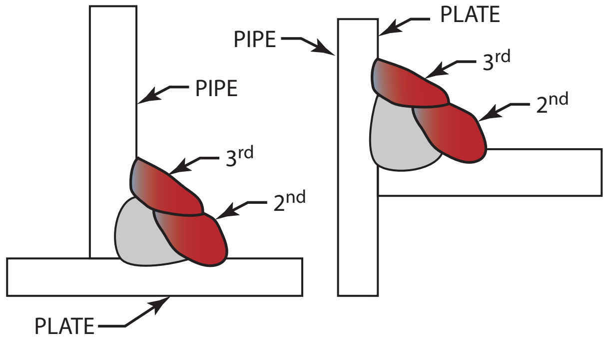


FIGURE 14-13 Third filler weld placement.

The third weld pass will complete the cover pass, and it will also be made using the spray metal transfer method. This weld should be made approximately one-half to two-thirds of the way up on the second weld's face, **Figure 14-13**. Chip and wire brush the weld each time you stop to reposition yourself. Visually inspect the weld, and discuss with your instructor what you need to do to improve your weld. Complete the weld all the way around the pipe.

Visually inspect the weld, and repeat this weld as needed with all three processes until you can consistently make welds free of defects. Turn off the welding machine and clean your work area when you are finished welding. Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 14-3

Fillet Weld, 5F Position, Using GMAW, FCAW-S, and FCAW-G

Using the same equipment and materials as Practice 14-1, you are going to make a fillet weld in the 5F fixed position using each of the three wire welding processes, **Figure 14-14**.

The weld will be made in an uphill progression, starting on the tack weld at the 6 o'clock position. Most welders stop on top of the tack weld at the 9 o'clock position. They do this so they can get in a better position to complete the weld.

The gun angle relative to the pipe surface will be constantly changing as the weld progresses upward. **Figure 14-15** shows how the gun angle starts at a slight

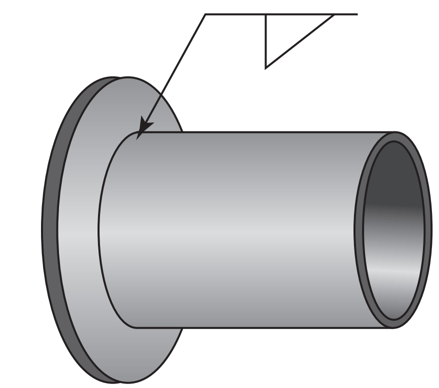


FIGURE 14-14 Horizontal fixed 5F fillet weld.

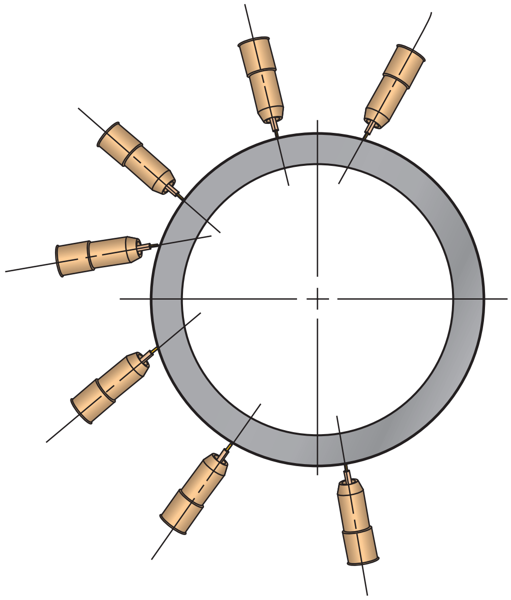


FIGURE 14-15 Gun angle changes for 5F and 5G welds.

forehand angle at 6 o'clock and becomes perpendicular to the pipe surface at approximately 7 o'clock. It transitions to a steep forehand angle of approximately 30° between 7 o'clock and 9 o'clock. Between 9 o'clock and 11 o'clock, the angle transitions back to perpendicular and remains perpendicular through the 12 o'clock position where the weld ends.

The weld bead should be made as an equal legged 3/16-in. (4.8-mm) fillet weld. Chip and wire brush the weld; after you visually inspect it, discuss with your instructor what you need to do to improve your root penetration before making the weld on the opposite side.

Visually inspect the weld, and repeat this weld as needed with all three processes until you can consistently make welds free of defects. Turn off the welding machine and clean your work area when you are finished welding. Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 14-4

Butt Joint, 1G Position, Using GMAW, FCAW-S, and FCAW-G

Using a properly set up and adjusted CP welding machine, proper safety protection, welding electrodes, and two or more pieces of schedule 40 mild steel pipe 6 in. to 8 in. (150 to 200 mm) in diameter, you will make a pipe butt joint in the 1G horizontal rolled position using each of the three wire welding processes, **Figure 14-16**. ◆

Tack Welds

Tack weld two pieces of pipe together with four 1-in. (25-mm)-long welds at the 12, 3, 6, and 9 o'clock positions as shown in **Figure 14-17**. Grind the ends of the tack welds before placing the pipe horizontally on the welding table or pipe stand with the top tack welds between the 10:30 and 1:30 o'clock positions.

Root Pass

Start welding at the 1:30 o'clock position and weld to the 10:30 o'clock position with a 14° to 20° forehand angle in the direction of travel. The root pass is made as a stringer bead with the GMA welding process unless a backing ring is used; then, it can be made with the FCA welding process.

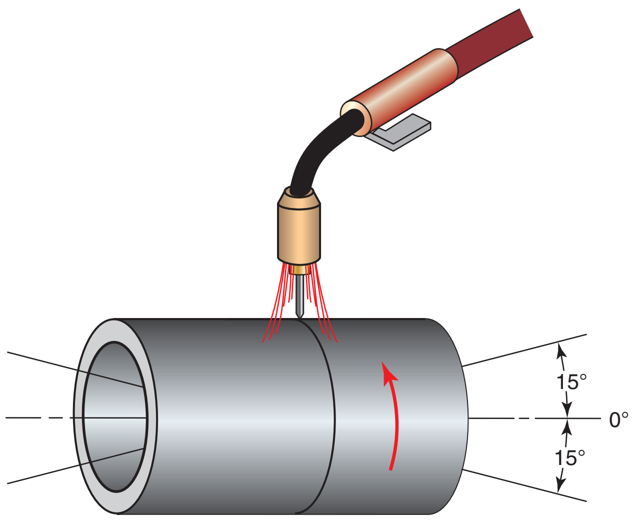


FIGURE 14-16 1G position.

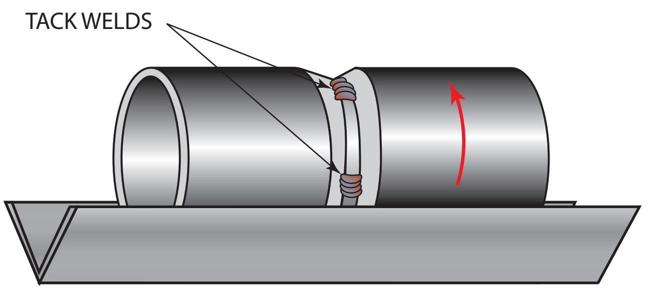


FIGURE 14-17 Aligning pipe for tack welding.

As you pass over the top of the pipe and start downhill, change to a slight backhand angle that will increase to approximately a 45° angle. Watch the leading edge of the molten weld pool to see if you have a keyhole, which indicates you are getting 100% penetration.

Visually inspect the root surface to see if you had 100% penetration. Mark any areas that did not have complete penetration so you can make changes in the next section to be welded. Discuss with your instructor what you need to do to improve your root penetration.

Rotate the pipe so you can make the next root weld. Make the necessary changes in the machine settings before starting the next weld. Repeat this process until you have made the root pass all the way around the pipe. Clean the root and grind any areas that need additional cleanup.

NOTE

The small weld coupon may become too hot to allow you to make a good weld. Be sure to give the coupon time to cool between weld passes. You may want to have two or three coupons being worked on at the same time so you can alternate between the three processes as a way of giving the coupon time to cool.

Hot Pass

The hot pass is made with the same procedure of welding from the 1:30 to 10:30 o'clock positions as the root pass. Watch the sides of the groove and the leading edge of the molten weld pool to make sure it is being fused.

Clean the weld face and visually inspect it for uniformity and sidewall fusion. Grind any trapped slag, and taper the end of the weld to make it easier to restart the weld bead. Discuss with your instructor what you need to do to improve your root penetration.

Rotate the pipe so you can make the next hot pass weld. Make the necessary changes in the machine settings before starting the next weld. Repeat this process until you have made the hot pass all the way around the pipe.

Grind any areas of the hot pass that have buildup greater than 1/8 in. (3 mm) higher than the surrounding weld face before starting the filler passes.

Filler Pass(es)

The first filler pass is made along one side so that its toe is approximately two-thirds of the way across the hot pass. If the toe of the filler pass is made so it meets the opposite sidewall, then the V it forms will be likely to trap slag, and it is difficult to get the next filler pass to penetrate the narrow gap it forms, **Figure 14-18**.

The end of the filler passes can be tapered down by slightly increasing the welding travel speed and reducing the weave pattern. This will make it easier to restart the next weld bead. When you have reached the 10:30 o'clock position, stop welding, clean off the flux, and visually

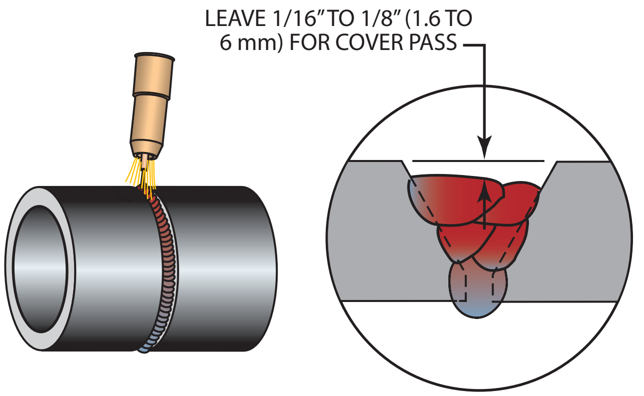


FIGURE 14-18 Leave adequate space for the cover pass.

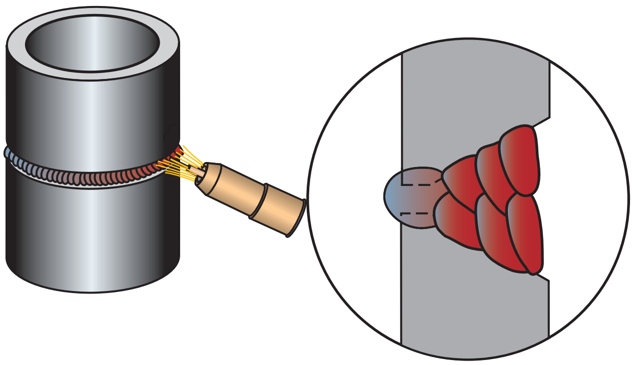


FIGURE 14-19 Filler weld sequence for 2G position.

inspect the weld. Discuss with your instructor what you need to do to improve your root penetration.

Rotate the pipe so you can make the next filler pass. Make the necessary changes in the machine settings before starting the next weld. Repeat this process until you have filled the weld groove to within approximately 1/16 to 1/8 in. (1.6 to 3 mm) below the pipe's outer surface. Clean the weld, and grind any starts or stops that are more than 1/16 in. (1.6 mm) higher than the surrounding weld surface. Also, grind any areas of the weld that are overfilled that would affect the uniformity of the cover weld pass.

Cover Pass

Watch the edge of the groove as the first cover pass weld is made so that it does not overlap the edge more than 1/16 in. (1.6 mm). Bracing yourself on the table or bracing your hand on the pipe will help you make the cover pass more consistent. The transition for the pipe surface to the weld must be smooth and uniform, so do not spend too much time along the side of the groove because that could cause excessive reinforcement and an abrupt toe of the weld.

Clean each weld before the next weld is started. When the cover weld has been completed, clean the weld, do not grind it, and inspect it for discontinuities or defects. Repeat this weld as needed with all three processes until you can consistently make welds free of defects. Turn off the welding machine and clean your work area when you are finished welding. Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 14-5

Butt Joint, 2G Position, Using GMAW, FCAW-S, and FCAW-G

Using the same equipment and materials as Practice 14-4, you are going to make a V-grooved weld in the 2G vertical fixed position using each of the three wire welding processes. Prepare the pipe and tack it together as before, and then place it vertically on the table or on a pipe stand.

You will use a 14° to 20° forehand angle in the direction of travel for the root pass and the same forehand angle with a 5° to 10° upward work angle for all of the additional weld passes, Figure 14-11. This upward work angle will help to prevent the weld bead's bottom edge from sagging.

Keeping the weld beads small makes it easier to control the molten weld pool. Place the weld beads in the groove as illustrated in **Figure 14-19**. Repeat this weld as needed with all three processes until you can consistently make welds free of defects. Turn off the welding machine and clean your work area when you are finished welding. Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 14-6

Butt Joint, 5G Position, Using GMAW, FCAW-S, and FCAW-G

Using the same equipment and materials as Practice 14-4, you are going to make a V-grooved weld in the 5G fixed position using each of the three wire welding processes. Prepare the pipe and tack it together as before, and place it horizontally on a pipe stand. Any time the weld has to be stopped, the weld must be cleaned and the end of the weld bead must be feathered, even if the weld stops on a tack weld.

These welds will be made in an uphill progression, starting near the 6 o'clock position. Most welders stop on top of the tack weld at the 9 o'clock position. They do this so they can get in a better position to complete the weld.

This weld transitions from the overhead position to the vertical position and then to the flat position. Therefore, the gun angle relative to the pipe surface must be constantly changing as the weld progresses upward. Figure 14-15 shows how the gun angle starts at a slight forehand angle at 6 o'clock and becomes perpendicular to the pipe surface at approximately 7 o'clock. It transitions to a steep forehand angle of approximately 30° between 7 and 9 o'clock. Between 9 and 11 o'clock, the angle transitions back to perpendicular and remains perpendicular through the 12 o'clock position where the weld ends.

Clean the weld and feather the starting and stopping points. Chip and wire brush the root pass before visually inspecting it for any problem areas with lack of fusion, excessive buildup, burnthrough, or other discontinuity. Discuss with

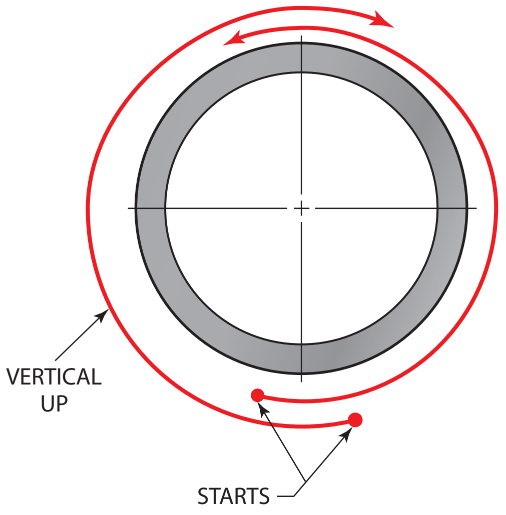


FIGURE 14-20 Stagger the starts and stops.

your instructor what you need to do to improve your root penetration before making the weld on the opposite side.

Grind the root pass to remove any trapped slag and deep undercut before starting the hot pass. The beginning and ending points of all of the weld should be staggered so they are not all in the same area and overlap, **Figure 14-20**. Slightly increasing the voltage or decreasing the wire-feed speed can help to make the weld pool a little more fluid and help increase the hot pass penetration. Use the same technique of transitioning the electrode angle as you used on the root pass to make the hot pass. Use a stringer technique with little or no weave for most of the weld. A slight weave may be needed to fill any area that was ground out to remove root pass undercut.

Chip and wire brush the root pass before visually inspecting the hot pass for any problem areas with lack of fusion, excessive buildup, or other discontinuity. Discuss with your instructor what you need to do to improve your root penetration before making the weld on the opposite side.

When the hot pass is completed, clean and wire brush it before showing it to your instructor for their advice. Grind any areas of the hot pass that have a weld buildup greater than 1/8 in. (3 mm) before starting the filler passes. Slightly reduce the voltage or increase the wire-feed speed so that the weld has good fusion but not deep penetration because the filler passes do not need to have deep penetration.

The first filler pass can be made by rocking the welding gun so that the arc is directed from side to side or by using a slight side-to-side weave, **Figure 14-21**. This can make a concave weld that can make it easier to prevent slag entrapment and/or undercut along the toe of the weld. If this technique is used, it is important not to make the weave too large because that can cause excessive buildup and overlap.

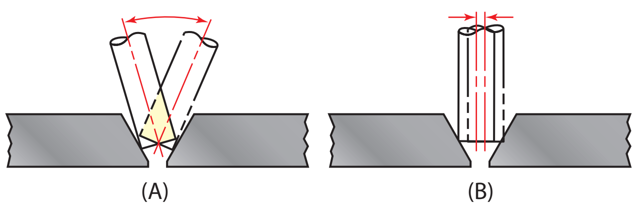


FIGURE 14-21 (A) Rocking the electrode. (B) Side-to-side weaving.

Whether you used a slight weave or stringer bead for the first filler pass, all of the following passes should be made as stringer beads. Remember to grind the ends of the welds before restarting the next weld. Also, clean and grind any part of a weld bead that has undercut, overlap, or slag trapped before making the next weld pass.

The groove must be left with 1/16 to 1/8 in. (1.6 to 3 mm) below the surface so that there will be room for the cover pass. If necessary, grind away any areas of the filler passes that are too high or uneven that would affect the appearance of the cover passes.

Again, follow the edge of the V-groove for the first cover pass. Keep the weld bead small and uniform. Overlap each weld pass approximately one-third of the way. Judge the width of the weld beads so that the last weld pass will not overlap the edge of the V-groove more that 1/8 in. (3 mm). You may have a problem if the last weld pass needs to be much wider than the other cover pass welds, because trying to make it larger can cause overlap or excessive buildup.

Visually inspect the weld and repeat this weld as needed with all three processes until you can consistently make welds free of defects. Turn off the welding machine and clean your work area when you are finished welding. Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 14-7

Butt Joint, 6G Position, Using GMAW, FCAW-S, and FCAW-G

Using the same equipment and materials as Practice 14-4, you are going to make a V-grooved weld in the 6G fixed position using each of the three wire welding processes. Prepare the pipe and tack it together as before, and place it at a 45° angle on a pipe stand. Any time the weld has to be stopped, the weld must be cleaned and the end of the weld bead must be feathered, even if the weld stops on a tack weld.

The root pass is made without changing the work angle, because getting good root penetration is more important than trying to prevent the weld face from sagging to the downhill side of the groove. Any sagging can be removed by postweld grinding.

Once the root pass is made, the remaining welds in the 6G position become more challenging because both the electrode angle and the work angle must be constantly changed to maintain a consistent weld bead. That is because parts of the weld are much like the overhead portion of the 5G weld. Other parts are more like the 2G weld.

Slightly increase the voltage or decrease the wire-feed speed to help increase the weld penetration for the hot pass. Start the hot pass weld on the opposite side of the bottom that the root pass was started. Use a slight

forehand angle and an approximately 5° upward work angle when starting to weld, Figure 14-15. Transition to a perpendicular work angel at the 6 o'clock position with the same 5° upward work angle. As the weld progresses toward the 9 o'clock position, increase the forward gun angle to approximately 30° and keep the same 5° work angle. Between the 9 and 11 o'clock positions, transition to a perpendicular gun angle while keeping enough work angle to force the weld face to be uniform and not sagging toward the downhill side of the joint.

Clean and visually inspect the hot pass. Discuss with your instructor what you need to do to improve your hot pass before making the weld on the opposite side.

The filler passes will be made with a similar technique as the hot pass but with a little less penetration, so set the voltage and/or amperage for a less penetrating weld. The first filler welds will be made on the downhill side of the groove and cover approximately two-thirds of the hot pass weld surface. Each of the next filler welds will be made on the upper side of the previous filler welds, **Figure 14-22**. Remember to stagger the starts and stops as you make the filler welds.

Grind any areas of the filler pass that are not uniform in buildup or are excessively built up before starting the cover passes, **Figure 14-23** The cover passes are made with the same technique as the filler passes but with possibly a slightly greater work angle of between 5° and 10°. Keep the cover passes small so they can be controlled and kept uniform.

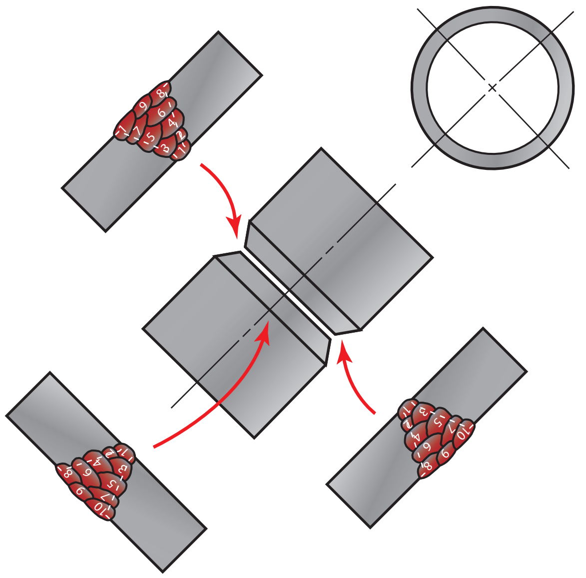


FIGURE 14-22 Welding bead sequence for 6G position.

Visually inspect the weld and repeat this weld as needed with all three processes until you can consistently make welds free of defects. Turn off the welding machine and clean your work area when you are finished welding. Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor.◆

Larry Jeffus

FIGURE 14-23 When grinding, be careful not to grind outside of the weld groove or to widen the weld groove.

Summary

The wire welding processes of GMA and FCA welding have become the standard process for many types of piping system construction. The speed and quality of welds that can be produced with these processes have contributed to their increasing share of the work. The silicon slag that some GMA welding filler metals leave on the surface of a weld must be cleaned off as completely as the slag left by any of the FCA filler metals.

FCAW-G has its limitations for working outdoors when there is anything but a very light breeze because the gas shielding can be easily disturbed. When this happens, the molten weld pool is not adequately protected, and the resulting weld will have discontinuities and may even be defective. If FCAW-G is to be used in the field, then a portable work tent must be used to insure that the weld is going to be shielded properly.

As you develop your welding skills, you will be able to control a larger molten weld pool and you can begin to make wider welds using a weave pattern.

Review

1. The ends of pipe are beveled at what angle?
2. How wide should the metal surface be ground clear beside the weld joint?
3. According to the API code, pipes of the same nominal diameter should be fitted so the offset is no greater than ________.
4. When cutting off a pipe coupon, why should you catch a pipe coupon with pliers before it hits the floor?
5. How many tack welds are required for a pipe joint?
6. Why are the ends of tack welds ground to a featheredge?
7. Why must the root weld be started on a tack weld?
8. What is the purpose of the hot pass?
9. How much space must be left in the groove so there will be room for the cover passes?
10. What is another name for the cover pass?
11. What is the maximum acceptable depth of undercut on a finished weld?
12. What type of weld would be used to join a socket joint to pipe?
13. What is used to grind the ends of a tack weld to a featheredge?
14. Why should you grind the starting point of the first weld?
15. What can be done if there is undercut along the toe of a fillet weld in the 2F position?
16. What should the gun angle be at when starting the root pass on a 1G weld at the 1:30 o'clock position?
17. Why would it be a good idea to increase the welding travel speed as a filler weld is being ended?
18. How much should the first cover pass weld overlap the edge of the weld groove?
19. Why does the gun angle have to be constantly changing when making a 5G weld?
20. Why should the cover pass be kept small on 6G welds?

Chapter 15

Gas Metal Arc and Flux Cored Arc Welding AWS SENSE Certification

OBJECTIVES

After completing this chapter, the student should be able to

- demonstrate the ability to pass a bend test in butt, tee, and lap joints on sheet metal.
- demonstrate the ability to pass the SENSE GMAW short-circuit workmanship sample.
- demonstrate the ability to pass the bend test on a V-groove weld.
- demonstrate the ability to make AWS SENSE quality welds using FCAW-G and FCAW-S.

KEY TERMS

acceptance criteria
electrical characteristics
hydrocarbons
interpass temperature
keyhole
specimen preparation

INTRODUCTION

Welders are often required to take a qualification test. The type of joint, thickness of metal, type and size of filler metal, shielding gas, if any, and position are all specified by agencies issuing codes and standards. Except for the American Welding Society's (AWS) SENSE Welder program, which has gained wide acceptance in the welding industry, taking a test according to one company's or agency's specifications may not qualify a welder for another company's or agency's testing procedures. But being able to pass one type of test will usually help the welder to pass other tests for the same type of joint, thickness of metal, type and size of electrode, and position. Information about the AWS SENSE Certified Welder program is available from the AWS's main office in Miami, Florida.

The GMA and FCA welding processes are used to rapidly produce high-quality welds. The practices in this chapter are designed to further develop your GMA and FCA welding skills that you learned in Chapters 4 and 5. The welds that would qualify you, if passed, for a SENSE certification are identified as either "AWS SENSE Level I" or "AWS SENSE Level II" workmanship samples. The weld practices that are not part of the SENSE certification are designed to help you develop the skills needed to successfully pass the SENSE welds. The practices are designed to give you the experience of taking code-type tests in a variety of materials and positions even if you choose not to participate in the SENSE program. This chapter covers the high-quality welding of plate, pipe, and plate to pipe with both GMA and FCA welding processes.

PRACTICE WELDS

Some of the practice welds will be made with all three wire welding processes: GMAW, FCAW-S, and FCAW-G. Pipe welding Practice 15-13 has two possible positions and each can be welded with or without a backing. Also, Practices 15-14 and 15-15 have two positions each. You may want to try all of the variations for each of the workmanship standards.

The following information will apply to all of the practice welds in this chapter unless otherwise stated in the practice instructions. It is, however, possible to make changes in the filler metal or shielding gas specified if the ones listed are not available. Refer to the AWS SENSE Level I and Level II Specifications for Qualification and Certification for other consumables that meet the AWS guidelines.

Metal Preparation

All workmanship parts must be machine torch cut with OFC or PAC or mechanically cut. The welding groove and plate surface within 1 in. (25 mm) must be mechanically cleaned (ground) to a bright finish.

Practice Weld Equipment and Consumables

You will need the following items for all of the practice welds: a properly setup CP welding machine with wire feeder, wire cutters or MIG pliers, channel lock-type pliers, a grinder, wire brush, chipping hammer, punch, and all the required PPE. The welds are to be made using the following filler metals and shielding gasses unless otherwise stated:

- GMA welds will be made using 0.035 or 0.045 diameter E70S-X filler metal with 75% Ar + 25% CO_2 or Ar + 2% to 5% O_2 shielding gas.
- Self-shielded FCA welds will be made with 0.035 or 0.045 diameter E71T-11.
- Gas-shielded FCA welds will be made with 0.035 or 0.045 diameter with 75% Ar + 25% CO_2 shielding gas.

PRACTICE 15-1

All Positions Butt Joint, Tee Joint, and Lap Joint

Using the recommended GMA welding practice equipment and two or more pieces of 10-gauge to 14-gauge thickness carbon sheet steel, you will make welded butt joints, tee joints, and lap joints in all four positions, **Figure 15-1**. These welds are similar to the ones required for the AWS SENSE Workmanship Sample in Practice 15-2.

- One at a time, tack weld the sheets together to form the joints and place them in the desired position on a welding stand.
- Starting at one end, run a 1/8-in. (3-mm) bead along the joint. Watch the molten weld pool and bead for signs it is increasing or decreasing in size. Make any necessary changes in your technique to keep the weld consistent.

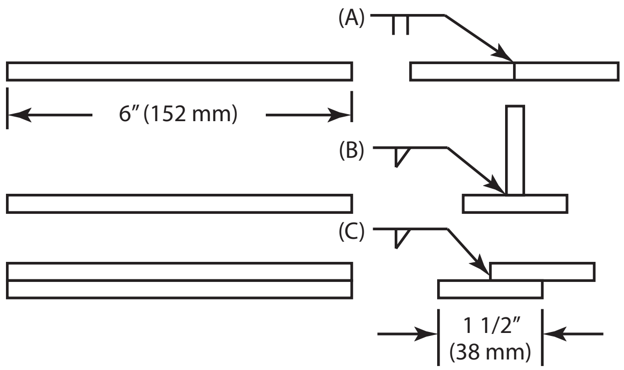


FIGURE 15-1 Layout for butt, tee, and lap joints.

- When the welds have cooled, use a hack saw or thermal cutting torch to cut out 1-in. (25-mm)-wide strips as shown in **Figure 15-2**.
- Using a vice and a hammer, bend the strip of welded joint as shown in **Figure 15-3**.

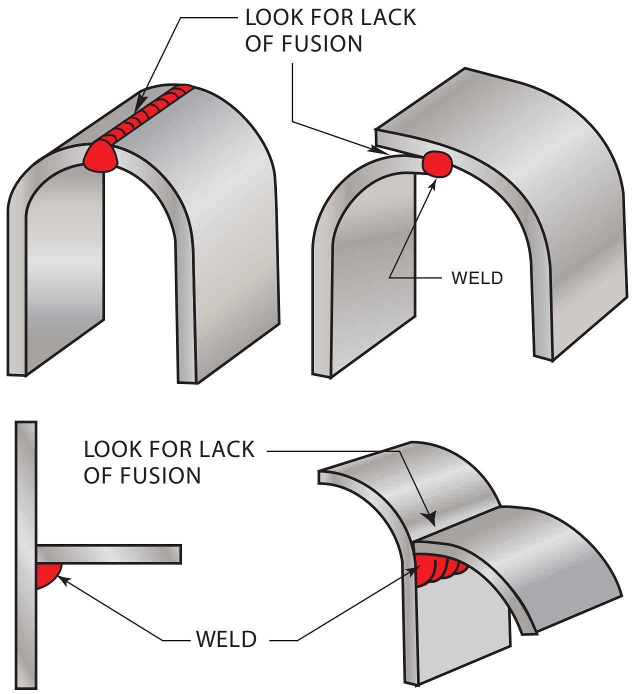


FIGURE 15-3 Method of bending test strips.

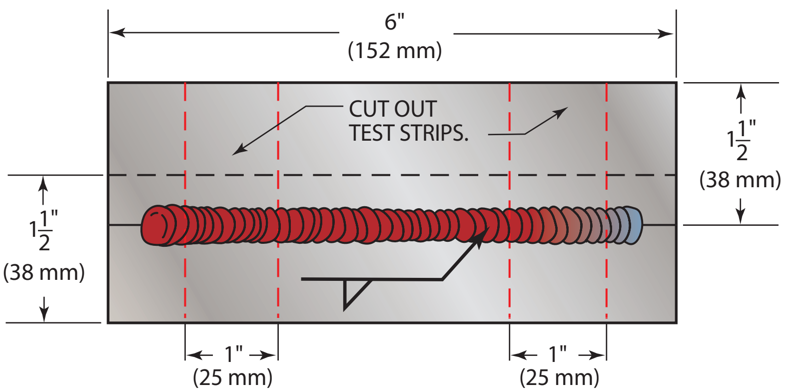


FIGURE 15-2 Location for the test strips.

- Check for complete root fusion on the lap and tee joints and 100% penetration on the butt joint.

Repeat each type of joint in each position as needed until consistently good beads are obtained. Turn off the welding machine and shielding gas and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 15-2 AWS SENSE

Gas Metal Arc Welding—Short-Circuit Metal Transfer (GMAW-S) Workmanship Sample

Welding Procedure Specification (WPS) No.: Practice 15-2.

Title:

Welding GMAW-S of carbon steel plate to carbon steel plate.

Scope:

This procedure is applicable for square 2G, 3G, and 4G groove and 3F, 3F, and 4F fillet welds within the range of 10 gauge (3.4 mm) through 14 gauge (1.9 mm) for the AWS SENSE Level I short-circuit metal transfer GMA welding.

Welding may be performed in the following positions:

All.

Base Metal:

The base metal shall conform to carbon steel M-1, P-1, and S-1 Group 1 or 2.

Backing Material Specification:

None.

Filler Metal:

The filler metal shall conform to AWS specification number. E70S-X from AWS specification A5.18. This filler metal falls into F-number F-6 and A-number A-1.

Shielding Gas:

The shielding gas, or gases, shall conform to the following compositions and purity: 25% CO_2 + 75% Ar at 30 to 50 cfh or Ar + 2% to 5% O_2 at 30 to 50 cfh.

Joint Design and Tolerances:

Refer to the drawing in **Figure 15-4** for the joint layout specifications.

Preparation of Base Metal:

All parts may be mechanically cut or machine PAC unless specified as manual PAC.

All **hydrocarbons** and other contaminants, such as cutting fluids, grease, oil, and primers, must be cleaned off all parts and filler metals before welding. This cleaning can be done with any suitable solvents or detergents. The groove face and inside and outside plate surfaces within 1 in. (25 mm) of the joint must be mechanically cleaned of slag, rust, and mill scale. Cleaning must be done with a wire brush or grinder down to bright metal.

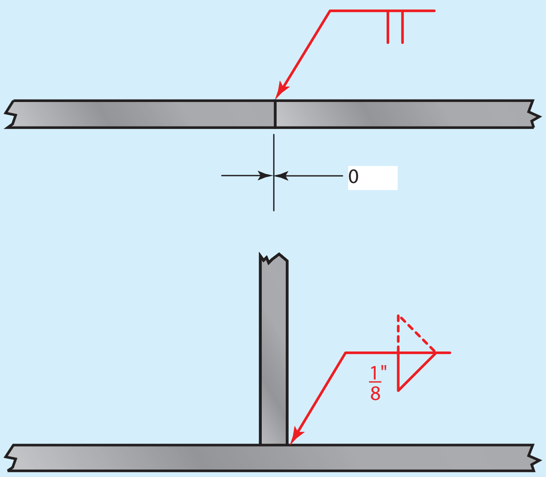


FIGURE 15-4 Practice 15-2 joint design.

Electrode		Welding Power			Shielding Gas		Base Metal	
Type	Size	Amps	Wire-Feed Speed IPM (cm/min)	Volts	Type	Flow	Type	Thickness
E70S-X	0.035 in. (0.9 mm)	90 to 120	180 to 300 (457 to 762)	15 to 19	CO_2 or 75% Ar/25% CO_2	30 to 50	Low carbon steel	1/4 in. to 1/2 in. (6 mm to 13 mm)
E70S-X	0.045 in. (1.2 mm)	130 to 200	125 to 200 (318 to 508)	17 to 20	CO_2 or 75% Ar/25% CO_2	30 to 50	Low carbon steel	1/4 in. to 1/2 in. (6 mm to 13 mm)

TABLE 15-1 GMAW-S Machine Settings

Electrical Characteristics:

Set the voltage, amperage, wire-feed speed, and shielding gas flow according to **Table 15-1**.

Preheat:

The parts must be heated to a temperature higher than 50°F (10°C) before any welding is started.

Backing Gas:

N/A.

Safety:

Proper protective clothing and equipment must be used. The area must be free of all hazards that may affect the welder or others in the area. The welding machine, welding leads, work clamp, electrode holder, and other equipment must be in safe working order.

Welding Technique:

Using a 1/2-in. (13-mm) or larger gas nozzle for all welding, first tack weld the plates together according to the drawing, **Figure 15-5**. Use the E70S-X filler metal to fuse the plates together. Clean any silicon slag, being sure to remove any trapped silicon slag along the sides of the weld.

All welds are to be made with one pass. All welds must be placed in the orientation shown in the drawing.

Interpass Temperature:

The plate should not be heated to a temperature higher than 350°F (175°C) during the welding process. After each weld pass is completed, allow it to cool but never to a temperature below 50°F (10°C). The weldment must not be quenched in water.

Cleaning:

The weld beads may be cleaned by a hand wire brush, a chipping hammer, or a punch and hammer. All weld cleaning must be performed with the test plate in the welding position.

Visual Inspection:

Visually inspect the weld for uniformity and discontinuities.

1. There shall be no cracks and no incomplete fusion.
2. There shall be no incomplete joint penetration in groove welds except as permitted for partial joint penetration welds.
3. The Test Supervisor shall examine the weld for acceptable appearance and shall be satisfied that the welder is skilled in using the process and procedure specified for the test.
4. Undercut shall not exceed the lesser of 10% of the base metal thickness or 1/32 in. (0.8 mm).
5. Where visual examination is the only criterion for acceptance, all weld passes are subject to visual examination at the discretion of the Test Supervisor.
6. The frequency of porosity shall not exceed one in each 4 in. (100 mm) of weld length, and the maximum diameter shall not exceed 3/32 in. (2.4 mm).
7. Welds shall be free from overlap.

Sketches:

GMAW Short-Circuit Metal Transfer Workmanship Sample drawing, **Figure 15-6**.

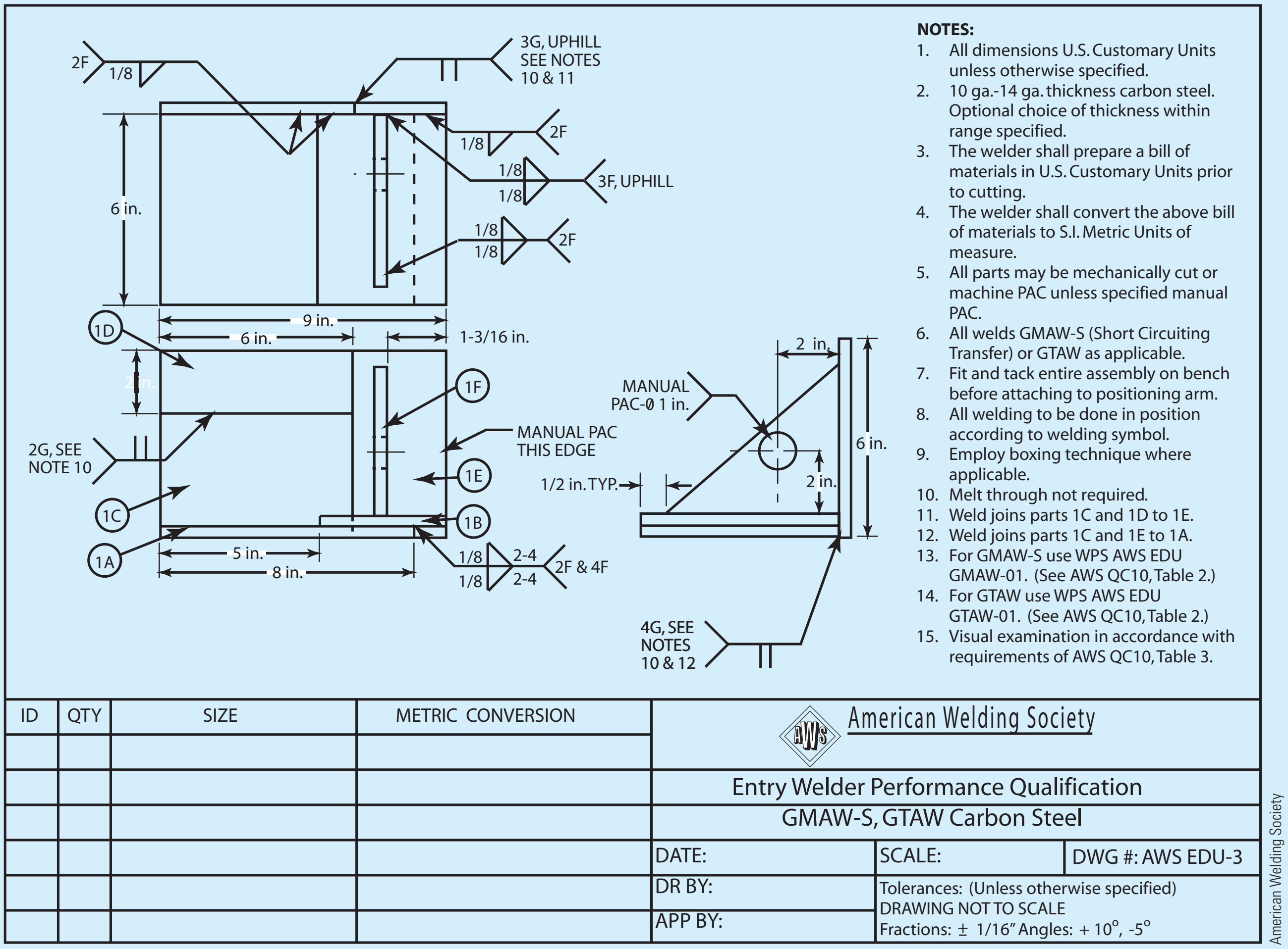


FIGURE 15-5 Practice 15-2 AWS SENSE GMAW Short-Circuit Metal Transfer Workmanship for carbon steel plate.

Paperwork:

Complete a "Bill of Materials," "Time Sheet," and "Performance Qualification Test Record" in Appendix I or as provided by your instructor. ◆

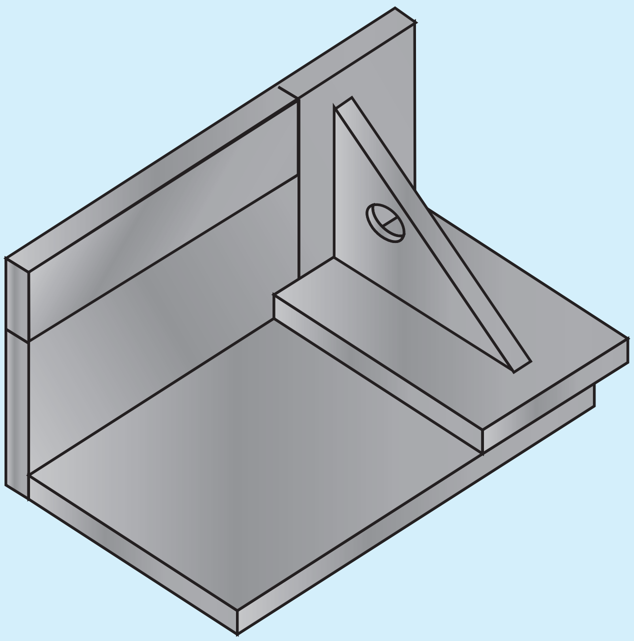


FIGURE 15-6 Practice 15-2 workmanship sample.

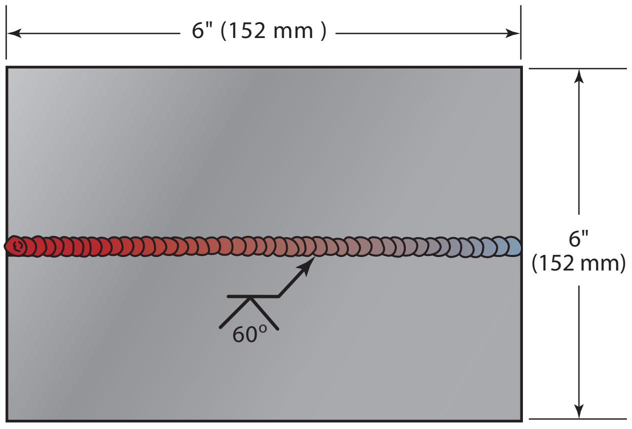


FIGURE 15-7 Practice 15-3 joint design.

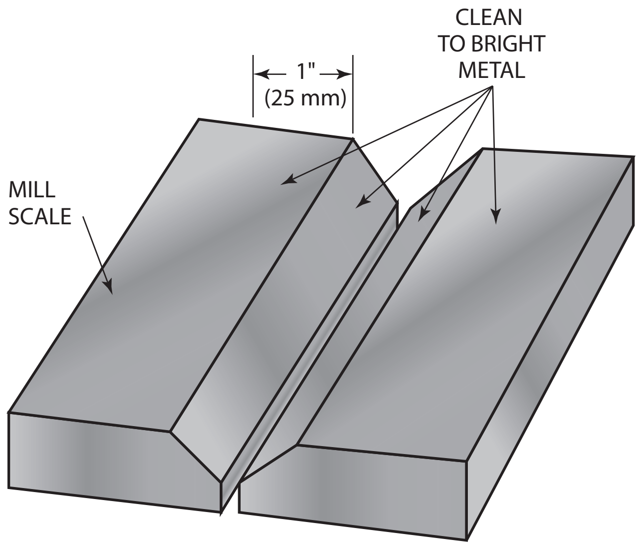


FIGURE 15-8 Practice 15-3 workmanship sample specifications.

PRACTICE 15-3

V-Groove Butt Joint 1G

Using the recommended GMA welding practice equipment, two or more pieces of mild steel plate, and 6-in. (152-mm)-long, 3-in. (76-mm)-wide, and 3/8-in. (9.5-mm)-thick beveled plate, you will make V-groove welds in the flat position using the spray metal transfer technique, **Figure 15-7.** These welds are similar to the ones required for the AWS SENSE Workmanship Sample in Practices 15-5 and 15-6.

THINK GREEN

Sometimes when test plates are being beveled with a torch, the plates may warp causing the beveled edge not to be straight. If this happens, do not discard the plate; you can use a grinder to rework the beveled edge to make it fit properly.

- The 30° bevel angles are to be flame or plasma cut on the edges of the plate before the parts are assembled.
- Grind a 1/16-in. (1.6 mm) to 1/8-in. (3 mm) root face on the beveled edge.
- The groove face and inside and outside plate surfaces within 1 in. (25 mm) of the joint must be mechanically cleaned of slag, rust, and mill scale, **Figure 15-8.** Cleaning must be done with a wire brush or grinder down to bright metal.
- Set the voltage, amperage, wire-feed speed, and shielding gas flow according to **Table 15-2**.
- Tack weld the plates with a root gap between the plates that measures approximately 1/16 in. to 1/8 in. (1.6 mm to 3 mm).
- Place the plates in position at a comfortable height and location. Be sure you have complete and free movement along the full length of the weld joint. It is often a good idea to make a practice pass along the joint with the welding gun without power to make sure nothing will interfere with your making the weld. Be sure the welding cable is free and will not get caught on anything during the weld.
- Grind the ends of the tack welds with a thin grinding disk.
- Using 20° to 30° backhand technique, start the weld at the very end of the groove. Allow the weld pool to expand to approximately 1/4-in. to 3/8-in. (6 mm to 9.5 mm) wide before starting to travel along the

Electrode		Welding Power			Shielding Gas		Base Metal	
Type	Size	Amps	Wire-Feed Speed IPM (cm/min)	Volts	Type	Flow	Type	Thickness
E70S-X	0.035 in. (0.9 mm)	180 to 230	400 to 550 (1016 to 1397)	25 to 27	Ar plus 2% O_2 or 90% Ar/10% CO_2	30 to 50	Low carbon steel	1/4 in. to 1/2 in. (6 mm to 13 mm)
E70S-X	0.045 in. (1.2 mm)	260 to 340	300 to 500 (762 to 1270)	25 to 30	Ar plus 2% O_2 or 90% Ar/10% CO_2	30 to 50	Low carbon steel	1/4 in. to 1/2 in. (6 mm to 13 mm)

TABLE 15-2 GMAW Spray Metal Transfer Machine Settings

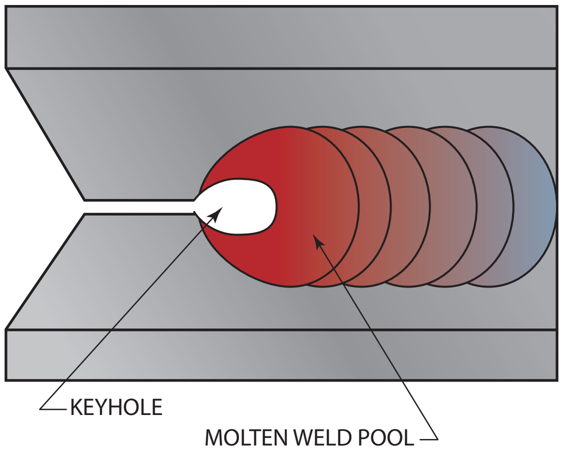


FIGURE 15-9 Having a key hole at the leading edge of the molten weld pool is a good indication that the joint will have 100% root penetration.

groove. Watch the leading edge of the weld pool for a **keyhole** that indicates that you are getting 100% penetration, **Figure 15-9**.

- When the weld reaches the opposite end, pause long enough for the weld crater to fill up, so the end of the weld is all the way to the edge of the plates.
- Clean off all of the slag with a wire brush, chipping hammer, or punch.
- It should take three or more weld passes to fill the groove. The cover pass should be no more than 1/8 in. (3 mm) wider than the groove, and the reinforcement should be no more than 1/8 in. (3 mm) above the plate's surface.

Repeat with both classifications of electrodes as needed until consistently defect-free welds can be made. Turn off the welding machine and shielding gas and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 15-4

Fillet Weld Tee Joint 1F

Using the recommended GMA welding practice equipment and two or more pieces of mild steel plate 6 in. (152 mm) long, 3 in. (76 mm) wide, and 3/8 in. (9.5 mm) thick, you will make a tee joint with fillet welds in the horizontal position using the spray metal transfer technique. These welds are similar to the ones required for the AWS SENSE Workmanship Sample in Practice 15-5.

- The plate surfaces within 1 in. (25 mm) of the joint must be mechanically cleaned of slag, rust, and mill scale, Figure 15-8. Cleaning must be done with a wire brush or grinder down to bright metal.
- Set the voltage, amperage, wire-feed speed, and shielding gas flow according to Table 15-2.
- Tack weld the vertical piece in the center of the base plate, **Figure 15-10**. Make sure it is square and in the center of the base plate, **Figure 15-11**. Make tack welds on both sides of the tee joint.
- Place the plates in position at a comfortable height and location. Be sure you have complete and free movement along the full length of the weld joint.
- Using 20° to 30° backhand technique, start the weld at the very end of the joint. Allow the weld pool to expand to 1/4 in. (6 mm) in size before starting to travel along the joint. Watch the leading edge of the weld pool to make sure you are getting complete root fusion.
- When the weld reaches the opposite end, pause long enough for the weld crater to fill up, so the end of the weld is all the way at the edge of the plates.

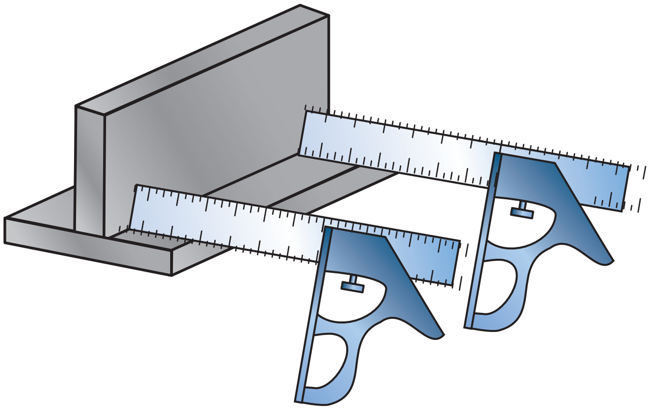


FIGURE 15-10 Accurate fitup is important for assembling workmanship standards.

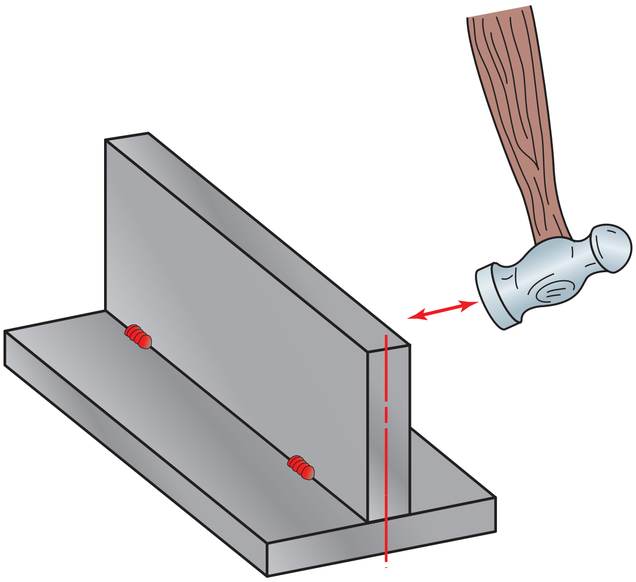


FIGURE 15-11 A hammer can be used to adjust the parts into squareness, if needed.

- Clean off all of the slag with a wire brush, chipping hammer, or punch.
- Make any adjustments in your machine setting and techniques that your instructor might suggest before making the second weld on the opposite side.

Repeat as needed until consistently defect-free welds can be made. Turn off the welding machine and shielding gas and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 15-5 AWS SENSE

Gas Metal Arc Welding (GMAW) Spray Transfer Workmanship Sample

Welding Procedure Specification (WPS) No.: Practice 13-5.

Title:

Welding GMAW of carbon steel plate to carbon steel plate.

Scope:

This procedure is applicable for V-groove and fillet welds on 3/8-in. (9.5-mm)-thick plate for the AWS SENSE Level I flat groove and horizontal fillet welds using spray transfer GMA welding.

Welding may be performed in the following positions:

1G and 2F.

Base Metal:

The base metal shall conform to carbon steel M-1, P-1, and S-1, Group 1 or 2.

Backing Material Specification:

None.

Filler Metal:

The filler metal shall conform to AWS specification no. 0.035 in. (0.90 mm) to 0.045 in. (1.2 mm) diameter E70S-X from AWS specification A5.18. This filler metal falls into F-number F-6 and A-number A-1.

Shielding Gas:

The shielding gas, or gases, shall conform to the following compositions and purity: 25% CO_2 + 75% Ar at 30 to 50 cfh or Ar + 2% to 5% O_2 at 30 to 50 cfh.

Joint Design and Tolerances:

Refer to the drawing in **Figure 15-12** for the joint layout specifications.

Preparation of Base Metal:

The 30° bevel angles are to be flame or plasma cut on the edges of the plate before the parts are assembled. The beveled surface must be smooth and free of notches. Any roughness or notches deeper than 1/64 in. (0.4 mm) must be ground smooth.

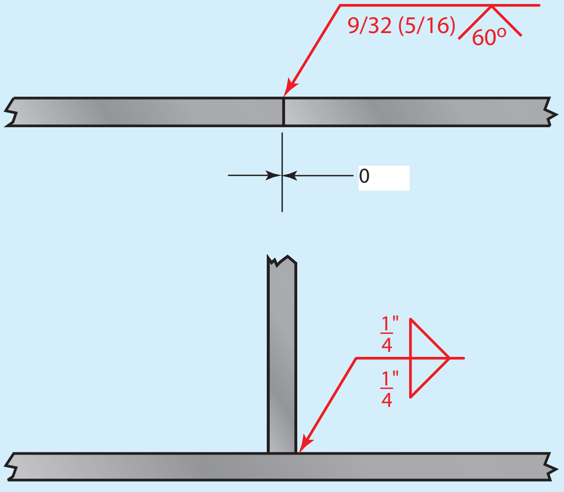


FIGURE 15-12 Practice 15-5 joint design.

All hydrocarbons and other contaminants, such as cutting fluids, grease, oil, and primers, must be cleaned off all parts and filler metals before welding. This cleaning can be done with any suitable solvents or detergents. The groove face and inside and outside plate surfaces within 1 in. (25 mm) of the joint must be mechanically cleaned of slag, rust, and mill scale. Cleaning must be done with a wire brush or grinder down to bright metal.

Electrical Characteristics:

Set the voltage, amperage, wire-feed speed, and shielding gas flow according to Table 15-2.

Preheat:

The parts must be heated to a temperature higher than 50°F (10°C) before any welding is started.

Backing Gas:

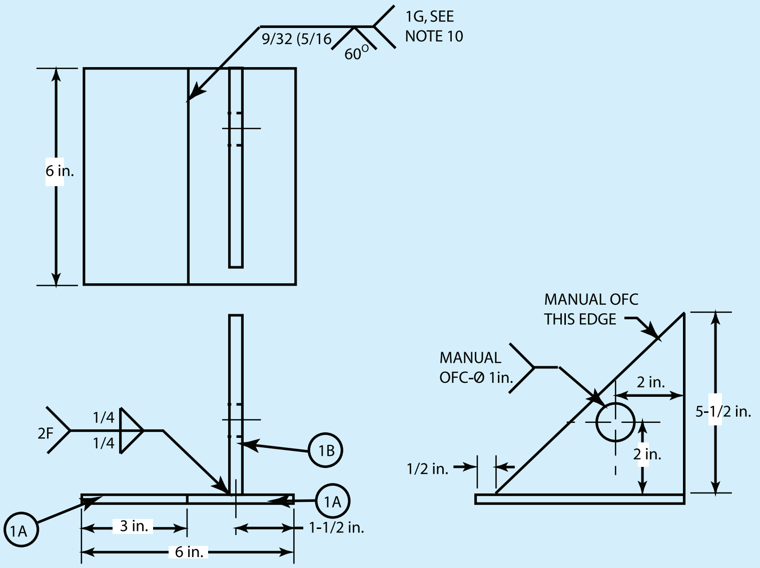
N/A.

Safety:

Proper protective clothing and equipment must be used. The area must be free of all hazards that may affect the welder or others in the area. The welding machine, welding leads, work clamp, electrode holder, and other equipment must be in safe working order.

Welding Technique:

Using a 3/4-in. (19-mm) or larger gas nozzle for all welding, first tack weld the plates together, **Figure 15-13**. Use the E70S-X arc welding electrodes to make the welds.



NOTES:

1. All dimensions U.S. Customary Units unless otherwise specified.
2. 3/8 in. thickness carbon steel.
3. The welder shall prepare a bill of materials in U.S. Customary Units of measure prior to cutting.
4. The welder shall convert the above bill of materials to S.I. Metric Units of measure.
5. All parts may be mechanically cut or machine OFC unless specified manual OFC.
6. All welds GMAW Spray Transfer.
7. Fit and tack entire assembly on bench before welding.
8. All welding to be done in position according to welding symbol.
9. Employ boxing technique where applicable.
10. Melt through not required.
11. Use WPS AWS EDU GMAW-02, AWS QC10, Table 2.
12. Visual examination in accordance with the requirements of AWS QC10, Table 3.

ID	QTY	SIZE	METRIC CONVERSION	American Welding Society		
				Entry Welder Performance Qualification		
				GMAW Spray Transfer, Carbon Steel		
				DATE:	SCALE:	DWG #: AWS EDU-2
				DR BY:	Tolerances: (Unless otherwise specified) DRAWING NOT TO SCALE Fractions: ± 1/16″ Angles: + 10°, -5°	
				APP BY:		

American Welding Society

FIGURE 15-13 Practice 15-5 AWS SENSE Gas Metal Arc Welding (GMAW) Spray Transfer Workmanship sample for 3/8-in. (9.5-mm)-thick steel plate.

Using the E70S-X arc welding electrodes, make a series of stringer filler welds no thicker than 1/4 in. (6.4 mm) in the groove until the joint is filled.

Interpass Temperature:

The plate should not be heated to a temperature higher than 350°F (175°C) during the welding process. After each weld pass is completed, allow it to cool but never to a temperature below 50°F (10°C). The weldment must not be quenched in water.

Cleaning:

Any slag must be cleaned off between passes. The weld beads may be cleaned by a hand wire brush, a chipping hammer, a punch, and hammer, or a needle scaler. All weld cleaning must be performed with the test plate in the welding position.

Visual Inspection:

Visually inspect the weld for uniformity and discontinuities.

1. There shall be no cracks and no incomplete fusion.
2. There shall be no incomplete joint penetration in groove welds except as permitted for partial joint penetration welds.
3. The Test Supervisor shall examine the weld for acceptable appearance and shall be satisfied that the welder is skilled in using the process and procedure specified for the test.
4. Undercut shall not exceed the lesser of 10% of the base metal thickness or 1/32 in. (0.8 mm).
5. When visual examination is the only criterion for acceptance, all weld passes are subject to visual examination at the discretion of the Test Supervisor.
6. The frequency of porosity shall not exceed one in each 4 in. (100 mm) of weld length and the maximum diameter shall not exceed 3/32 in. (2.4 mm).
7. Welds shall be free from overlap.

Sketches:

Gas Metal Arc Welding Spray Transfer (GMAW) Workmanship Sample drawing, **Figure 15-14**.

Paperwork:

Complete a "Bill of Materials," "Time Sheet," and "Performance Qualification Test Record" in Appendix I or as provided by your instructor. ◆

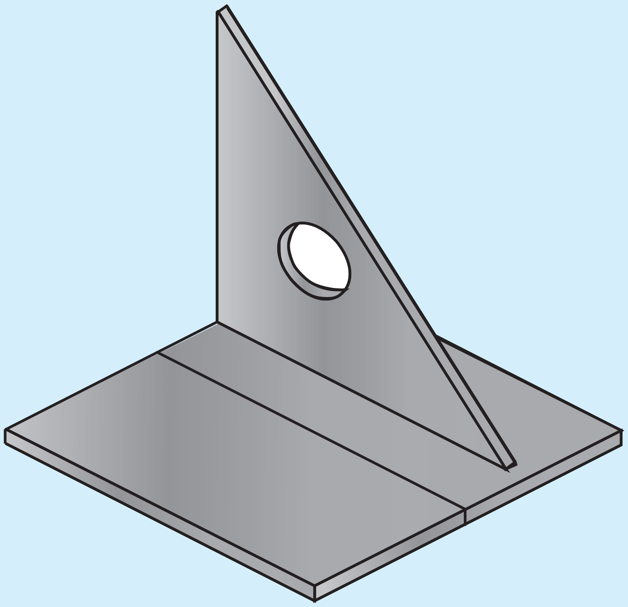


FIGURE 15-14 Practice 15-5 workmanship sample.

PRACTICE 15-6 AWS SENSE

Gas Metal Arc Welding (GMAW) Spray Transfer Workmanship Sample

Welding Procedure Specification (WPS) No.: Practice 15-4.

Title:

Welding GMAW of carbon steel plate to carbon steel plate.

Scope:

This procedure is applicable for V-groove weld on 1-in. (25-mm)-thick plate with backing for the AWS SENSE Level II flat groove weld using spray transfer GMA welding.

Welding may be performed in the following positions:

1G and 2F.

Base Metal:

The base metal shall conform to carbon steel M-1, P-1, and S-1, Group 1 or 2.

Backing Material Specification:

The backing metal strip shall conform to carbon steel M-1, P-1, and S-1, Group 1 or 2.

Filler Metal:

The filler metal shall conform to AWS specification no. 0.035 in. (0.90 mm) to 0.045 in. (1.2 mm) diameter E70S-X from AWS specification A5.18. This filler metal falls into F-number F-6 and A-number A-1.

Shielding Gas:

The shielding gas, or gases, shall conform to the following compositions and purity: 25% CO_2 + 75% Ar at 30 to 50 cfh or Ar + 2% to 5% O_2 at 30 to 50 cfh.

Joint Design and Tolerances:

Refer to the drawing in **Figure 15-15** for the joint layout specifications.

Preparation of Base Metal:

The 22 1/2° to 30° bevel angles are to be flame or plasma cut on the edges of the plate before the parts are assembled. The beveled surface must be smooth and free of notches. Any roughness or notches deeper than 1/64 in. (0.4 mm) must be ground smooth.

All hydrocarbons and other contaminants, such as cutting fluids, grease, oil, and primers, must be cleaned off all parts and filler metals before welding. This cleaning can be done with any suitable solvents or detergents. The groove face and inside and outside plate surface within 1 in. (25 mm) of the joint must be mechanically cleaned of slag, rust, and mill scale. Cleaning must be done with a wire brush or grinder down to bright metal.

Electrical Characteristics:

Set the voltage, amperage, wire-feed speed, and shielding gas flow according to Table 15-2.

Preheat:

The parts must be heated to a temperature higher than 50°F (10°C) before any welding is started.

Backing Gas:

N/A.

Safety:

Proper protective clothing and equipment must be used. The area must be free of all hazards that may affect the welder or others in the area. The welding machine, welding leads, work clamp, electrode holder, and other equipment must be in safe working order.

Welding Technique:

Using a 3/4-in. (19-mm) or larger gas nozzle for all welding, first tack weld the plates together, **Figure 15-16**. Use the E70S-X arc welding electrodes to make the welds.

Using the E70S-X arc welding electrodes, make a series of stringer filler welds no thicker than 1/4 in. (6.4 mm) in the groove until the joint is filled.

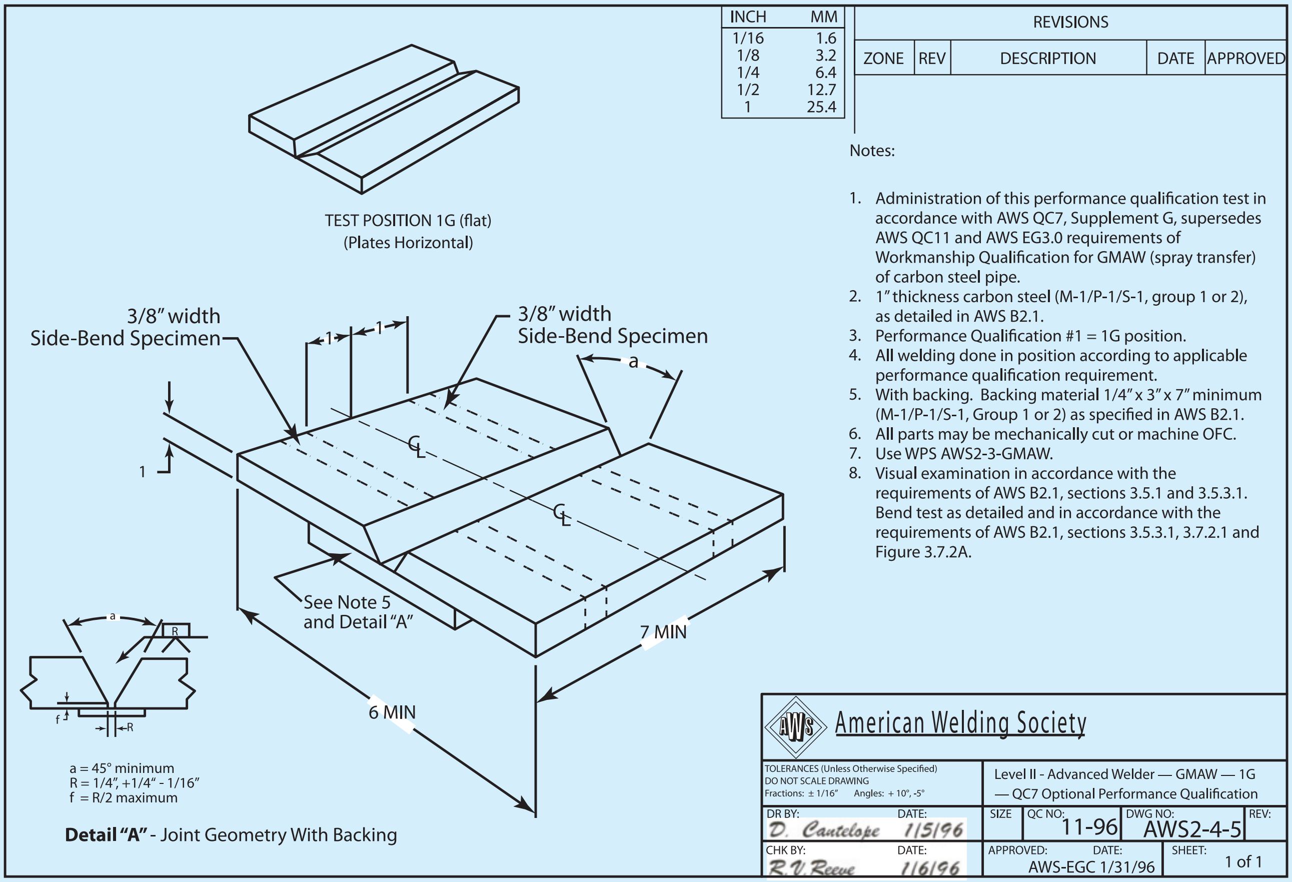


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FIGURE 15-15 Practice 15-6 AWS SENSE Gas Metal Arc Welding (GMAW) Spray Transfer Workmanship sample for 1-in. (25-mm)-thick steel plate.

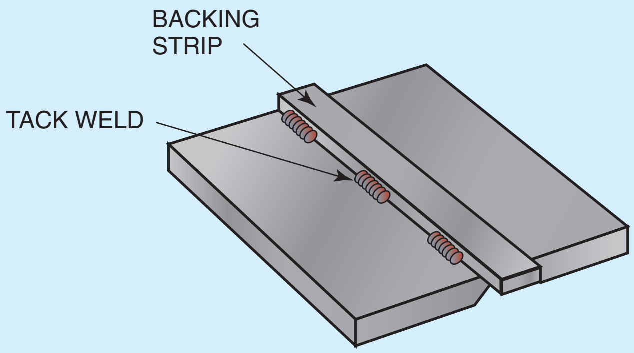


FIGURE 15-16 Practice 15-6 assembly.

Interpass Temperature:

The plate should not be heated to a temperature higher than 350°F (175°C) during the welding process. After each weld pass is completed, allow it to cool, but never to a temperature below 50°F (10°C). The weldment must not be quenched in water.

Cleaning:

Any slag must be cleaned off between passes. The weld beads may be cleaned by a hand wire brush, a chipping hammer, a punch, and hammer, or a needle scaler. All weld cleaning must be performed with the test plate in the welding position.

Visual Inspection:

There shall be no cracks and no incomplete fusion. There shall be no incomplete joint penetration in groove welds except as permitted for partial joint penetration welds.

- The Test Supervisor shall examine the weld for acceptable appearance and shall be satisfied that the welder is skilled in using the process and procedure specified for the test.
- Undercut shall not exceed the lesser of 10% of the base metal thickness or 1/32 in. (0.8 mm).
- Where visual examination is the only criterion for acceptance, all weld passes are subject to visual examination at the discretion of the Test Supervisor.
- The frequency of porosity shall not exceed one in each 4 in. (100 mm) of weld length, and the maximum diameter shall not exceed 3/32 in. (2.4 mm).
- Welds shall be free from overlap.

Bend Test:

The weld is to be mechanically tested only after it has passed the visual inspection. Be sure that the test specimens are properly marked to identify the welder, the position, and the process.

Specimen Preparation:

For 1/2-in. (13-mm) test plates, two side-bend specimens are to be located in accordance with the requirements in Figure 15-15.

- *Transverse side bend.* The weld is perpendicular to the longitudinal axis of the specimen and is bent so that the side of the weld face becomes the tension surface of the specimen.

***Acceptance Criteria for Bend Test*:**

For acceptance, the convex surface of the side of the weld bend specimen shall meet both of the following requirements:

- No single indication shall exceed 1/8 in. (3.2 mm) measured in any direction on the surface.
- The sum of the greatest dimensions of all indications on the surface that exceed 1/32 in. (0.8 mm) but are less than or equal to 1/8 in. (3.2 mm) shall not exceed 3/8 in. (9.5 mm).

Sketches:

Gas Metal Arc Welding Spray Transfer (GMAW) Workmanship Sample drawing, **Figure 15-17**.

Paperwork:

Complete a "Bill of Materials," "Time Sheet," and "Performance Qualification Test Record" in Appendix I or as provided by your instructor. ◆

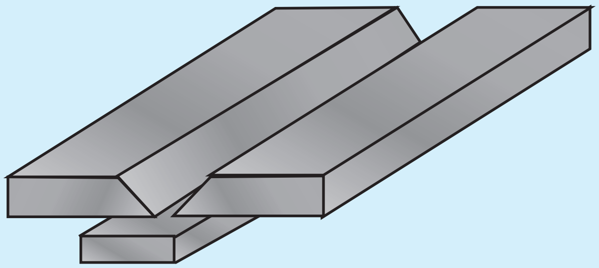


FIGURE 15-17 Practice 15-6 workmanship sample.

PRACTICE 15-7

V-Groove Butt Joint 1G and 3G Positions

Using the recommended FCA welding practice equipment, two or more pieces of mild steel plate, and 6-in. (152-mm) -long, 3-in. (76-mm)-wide, and 3/8-in. (9.5-mm)-thick beveled plate, you will make V-groove welds in the flat and vertical position using the FCAW-S and FCAW-G techniques. These welds are similar to the ones required for the AWS SENSE Workmanship Sample in Practice 15-11 and 15-12.

- The 30° bevel angles are to be flame or plasma cut on the edges of the plate before the parts are assembled, **Figure 15-18**.
- Grind a 1/16-in. (1.6 mm) to 1/8-in. (3 mm) root face on the beveled edge.
- The groove face and inside and outside plate surfaces within 1 in. (25 mm) of the joint must be mechanically cleaned of slag, rust, and mill scale, Figure 15-8. Cleaning must be done with a wire brush or grinder down to bright metal.

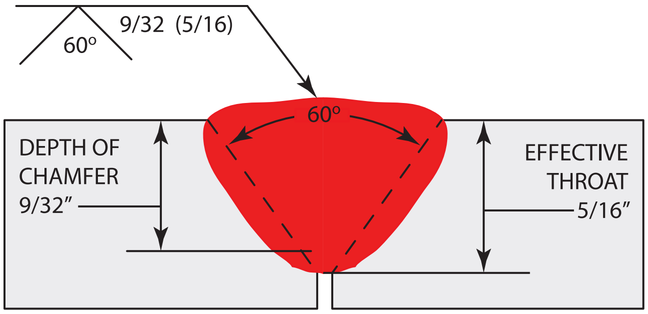


FIGURE 15-18 Practice 15-7 joint design.

- Set the voltage, amperage, wire-feed speed, and shielding gas flow according to **Table 15-3**.
- Tack weld the plates with a root gap between the plates that measures approximately 1/16 in. (1.6 mm).
- Place the plates in position at a comfortable height and location. Be sure you have complete and free movement along the full length of the weld joint.
- Using 20° to 30° backhand technique, start the weld at the very end of the groove. Allow the weld pool to expand to fill the full width of the groove wide before starting to travel along the groove.
- A slight weave pattern will help you control the molten weld pool in the 3G position.
- When the weld reaches the opposed end, pause long enough for the weld crater to fill up, so the end of the weld is all the way at the edge of the plates.
- Clean off all of the slag with a wire brush, chipping hammer, or punch.
- Make sure not to make the weld any wider than 1/8 in. (3 mm) than the groove and no more than 1/8 in. (3 mm) of reinforcement.

Repeat with both FCAW-G and FCAW-S as needed until consistently defect-free welds can be made. Turn off the welding machine and shielding gas and clean your work area when you are finished welding.

Complete a copy of the “Student Welding Report” listed in Appendix I or provided by your instructor. ◆

PRACTICE 15-8

Bevel Groove Butt Joint 2G

Using the recommended FCA welding practice equipment and two or more pieces of mild steel plate 6 in. (152 mm) long, 3 in (76 mm) wide, and 3/8 in. (9.5 mm) thick, you will make a beveled grooved butt joint in the horizontal position using both the FCAW-G and FCAW-S processes. These welds are similar to the ones required for the AWS SENSE Workmanship Sample in Practices 15-11 and 15-12.

- The plate surfaces within 1 in. (25 mm) of the joint must be mechanically cleaned of slag, rust, and mill scale. Cleaning must be done with a wire brush or grinder down to bright metal.
- Set the voltage, amperage, wire-feed speed, and shielding gas flow according to Table 15-3 for FCAW-G and **Table 15-4** for FCAW-S.

Electrode		Welding Power			Shielding Gas		Base Metal	
Type	Size	Amps	Wire-Feed Speed IPM (cm/min)	Volts	Type	Flow	Type	Thickness
E71T-1	0.035 in. (0.9 mm)	130 to 150	288 to 380 (732 to 975)	22 to 25	CO_2 or 75% Ar/25% CO_2	30 to 50	Low carbon steel	1/4 in. to 1/2 in. (6 mm to 13 mm)
E71T-1	0.045 in. (1.2 mm)	150 to 210	200 to 300 (508 to 762)	28 to 29	CO_2 or 75% Ar/25% CO_2	30 to 50	Low carbon steel	1/4 in. to 1/2 in. (6 mm to 13 mm)

TABLE 15-3 GMAW Spray Metal Transfer Machine Settings

Electrode Type	Diameter	Volts	Amps	Wire-Feed Speed IPM (cm/min)	Electrode Stickout (in.)
Self-Shielded E70T-11 or E71T-11	0.030	15	40	69 (175)	3/8
		16	100	175 (445)	3/8
		16	160	440 (1118)	3/8
	0.035	15	80	81 (206)	3/8
		17	120	155 (394)	3/8
		17	200	392 (996)	3/8
	0.045	15	95	54 (137)	1/2
		17	150	118 (300)	1/2
		18	225	140 (356)	1/2

TABLE 15-4 FCAW Self-Shielded Machine Settings

- Tack weld the plates with a root gap between the plates that measures approximately 1/16 in. (1.6 mm).
- Place the plates in position at a comfortable height and location. Be sure you have complete and free movement along the full length of the weld joint.
- Using 20° to 30° backhand stringer bead technique, start the weld at the very end of the groove. Allow the root weld pool to expand to approximately 1/4 in. (6 mm) in width before starting to travel along the groove, **Figure 15-19A**.
- When the weld reaches the opposite end, pause long enough for the weld crater to fill up, so the end of the weld is all the way at the edge of the plates.
- Clean off all of the slag with a wire brush, chipping hammer, or punch.
- Use the same backhand technique but with a J weave pattern for the second weld, **Figure 15-20**. Place this weld bead on the bottom plate along its outside edge extending two-thirds of the way up the beveled surface, **Figure 15-19B**.
- Clean the weld.
- The cover pass is made with the same backhand technique with a J weave pattern and extends from the top edge of the bevel to almost the bottom edge, **Figure 15-19C**.

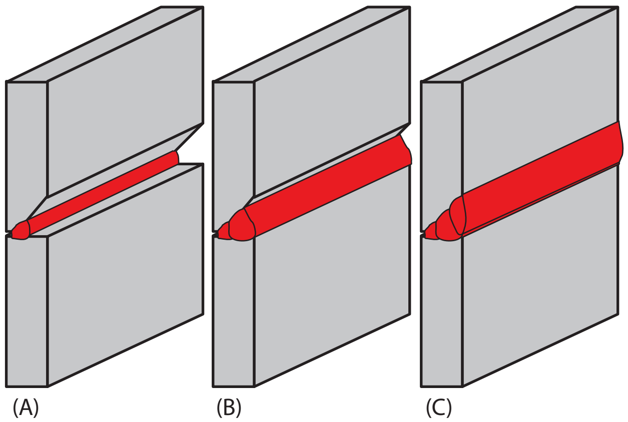


FIGURE 15-19 Practice 15-8 2G weld sequence.

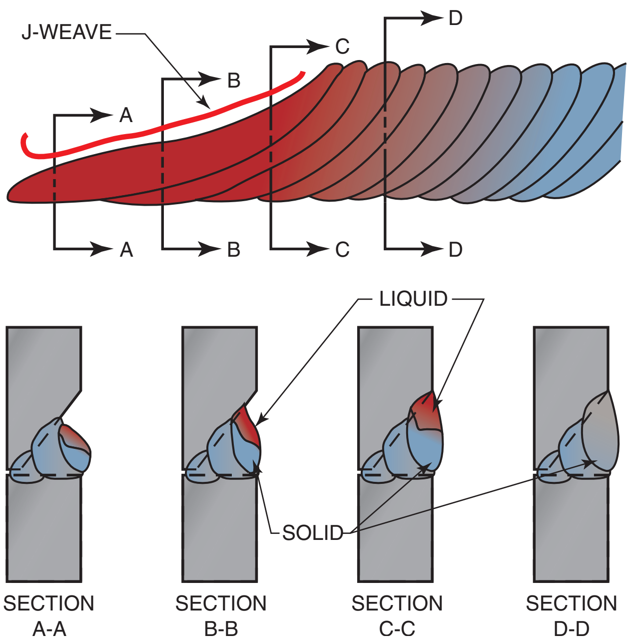


FIGURE 15-20 2G J-weave technique.

Repeat with both FCAW-G and FCAW-S as needed until consistently defect-free welds can be made. Turn off the welding machine and shielding gas and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 15-9

Bevel Groove Butt Joint 4G

Using the recommended FCA welding practice equipment and two or more pieces of mild steel plate 6 in. (152 mm) long, 3 in. (76 mm) wide, and 3/8 in. (9.5 mm) thick, you will make a beveled grooved butt joint in the overhead position using both the FCAW-G and FCAW-S processes. These welds are similar to the ones required for the AWS SENSE Workmanship Sample in Practices 15-11 and 15-12.

- The plate surfaces within 1 in. (25 mm) of the joint must be mechanically cleaned of slag, rust, and mill scale. Cleaning must be done with a wire brush or grinder down to bright metal.
- Set the voltage, amperage, wire-feed speed, and shielding gas flow according to Table 15-3 for FCAW-G and Table 15-4 for FCAW-S.
- Tack weld the plates with a root gap between the plates that measures approximately 1/16 in. (1.6 mm).
- Place the plates in position at a comfortable height and location. Be sure you have complete and free movement along the full length of the weld joint.
- Using 10° to 15° backhand stringer bead technique, start the weld at the very end of the groove. Allow the root weld pool to expand to approximately 1/4 in. (6 mm) in width before starting to travel along the groove, **Figure 15-21A**.
- When the weld reaches the opposite end, pause long enough for the weld crater to fill up, so the end of the weld is all the way at the edge of the plates.
- Clean off all of the slag with a wire brush, chipping hammer, or punch.
- Using a 15° to 25° backhand technique with a zigzag or semi-circle for the second weld, place this weld bead on the top of the root pass, **Figure 15-21B**.

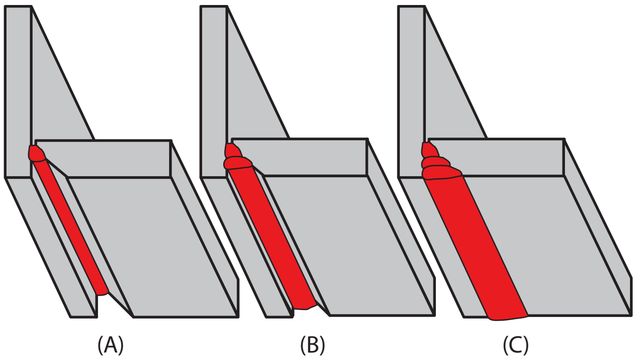


FIGURE 15-21 Practice 15-8 4G weld sequence.

- Clean the weld.
- The cover pass is made with a 15° to 25° backhand technique with a zigzag or semi-circle for the second weld, placing this weld bead on the top of the filler pass, **Figure 15-21C**. This weld can be made in two passes if you have trouble controlling the larger molten weld pool in the overhead position.

Repeat with both FCAW-G and FCAW-S as needed until consistently defect-free welds can be made. Turn off the welding machine and shielding gas and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 15-10

All Positions Fillet Welds on Lap Joint and Tee Joint

Using the recommended FCA welding practice equipment and two or more pieces of mild steel plate 6 in. (152-mm) long, 3 in. (76-mm) wide, and 3/8 in. (9.5-mm) thick, you will make welded lap joints and tee joints in all four positions using both the FCAW-G and FCAW-S processes. These welds are similar to the ones required for the AWS SENSE Workmanship Sample in Practices 15-11 and 15-12.

- One at a time, tack weld the sheets together to form the joints and place them in the desired position on a welding stand.
- Starting at one end, run a 1/4-in. (6 mm) equal leg fillet weld along the joint. Watch the molten weld pool and bead for signs it is increasing or decreasing in size. Make any necessary changes in your technique to keep the weld consistent.
- Check for complete root fusion on the lap and tee joints and 100% penetration on the butt joint.

Repeat each type of joint in each position with both FCAW-G and FCAW-S as needed until consistently defect-free welds can be made. Turn off the welding machine and shielding gas and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 15-11 AWS SENSE

AWS SENSE Entry-Level Welder Workmanship Sample for Flux Cored Arc Welding, Gas-Shielded (FCAW-G)

Welding Procedure Specification (WPS) No.: Practice 15-11.

Title:

Welding FCAW of plate to plate.

Scope:

This procedure is applicable for V-groove, bevel, and fillet welds within the range of 1/8 in. (3.2 mm) through 1 1/2 in. (38 mm) for the AWS SENSE Level I all-position groove and fillet welds using the FCAW-G welding process.

Welding may be performed in the following positions:

All.

Base Metal:

The base metal shall conform to carbon steel M-1, P-1, and S-1, Group 1 or 2.

Backing Material Specification:

None.

Filler Metal:

The filler metal shall conform to AWS specification no. E71T-1 from AWS specification A5.20. This filler metal falls into F-number F-6 and A-number A-1.

Shielding Gas:

The shielding gas, or gases, shall conform to the following compositions and purity: 25% CO_2 + 75% Ar at 30 to 50 cfh.

Joint Design and Tolerances:

Refer to the drawing and specifications in **Figure 15-22** for the workmanship sample layout.

Preparation of Base Metal:

The bevels are to be flame or plasma cut on the edges of the plate before the parts are assembled. The beveled surface must be smooth and free of notches. Any roughness or notches deeper than 1/64 in. (0.4 mm) must be ground smooth.

All hydrocarbons and other contaminants, such as cutting fluids, grease, oil, and primers, must be cleaned off all parts and filler metals before welding. This cleaning can be done with any suitable solvents or detergents. The groove face and inside and outside plate surfaces within 1 in. (25 mm) of the joint must be mechanically cleaned of slag, rust, and mill scale. Cleaning must be done with a wire brush or grinder down to bright metal.

Electrical Characteristics:

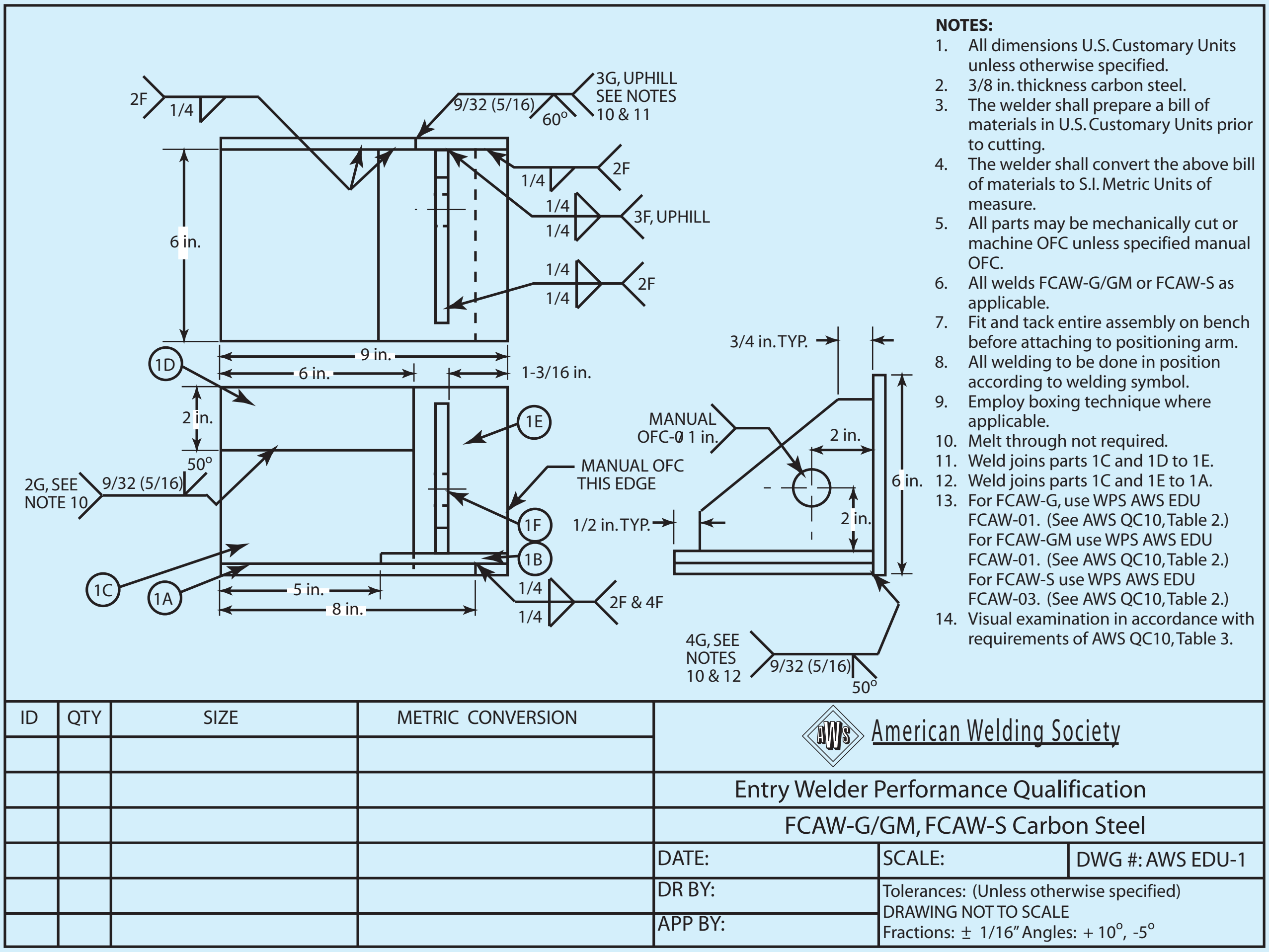
Set the voltage, amperage, wire-feed speed, and shielding gas flow according to Table 15-3.

Preheat:

The parts must be heated to a temperature higher than 50°F (10°C) before any welding is started.

Backing Gas:

N/A.



American Welding Society

FIGURE 15-22 Practices 15-11 and 15-12 AWS SENSE Flux Cored Arc Welding FCAW-G and FCAW-S Workmanship sample for steel plate.

Safety:

Proper protective clothing and equipment must be used. The area must be free of all hazards that may affect the welder or others in the area. The welding machine, welding leads, work clamp, electrode holder, and other equipment must be in safe working order.

Welding Technique:

Using a 1/2-in. (13-mm) or larger gas nozzle and a distance from contact tube to work of approximately 3/4 in. (19 mm) for all welding, first tack weld the plates together according to Figure 15-22. There should be a root gap of approximately 1/8 in. (3.2 mm) between the plates with V-grooved or beveled edges. Use an E71T-1 arc welding electrode to make a weld. If multiple pass welds are going to be made, then a root pass weld should be made to fuse the plates together. Clean the slag from the root pass, being sure to remove any trapped slag along the sides of the weld.

Using an E71T-1 arc welding electrode, make a series of stringer or weave filler welds no thicker than 1/4 in. (6.4 mm) in the groove until the joint is filled. The 1/4-in. (6.4-mm) fillet welds are to be made with one pass.

Interpass Temperature:

The plate should not be heated to a temperature higher than 350°F (175°C) during the welding process. After each weld pass is completed, allow it to cool, but never to a temperature below 50°F (10°C). The weldment must not be quenched in water.

Cleaning:

The slag must be cleaned off between passes. The weld beads may be cleaned by a hand wire brush, a chipping hammer, a punch, and hammer, or a needle scaler. All weld cleaning must be performed with the test plate in the welding position. A grinder may not be used to remove weld control problems such as undercut, overlap, or trapped slag.

Inspection:

Visually inspect the weld for uniformity and discontinuities. There shall be no cracks, no incomplete fusion, and no overlap. Undercut shall not exceed the lesser of 10% of the base metal thickness or 1/32 in. (0.8 mm). The frequency of porosity shall not exceed one in each 4 in. (100 mm) of weld length, and the maximum diameter shall not exceed 3/32 in. (2.4 mm).

Sketches:

Flux Cored Arc Welding (FCAW) Gas Shielded Workmanship Sample drawing, **Figure 15-23**.

Paperwork:

Complete a "Bill of Materials," "Time Sheet," and "Performance Qualification Test Record" in Appendix I or as provided by your instructor. ◆

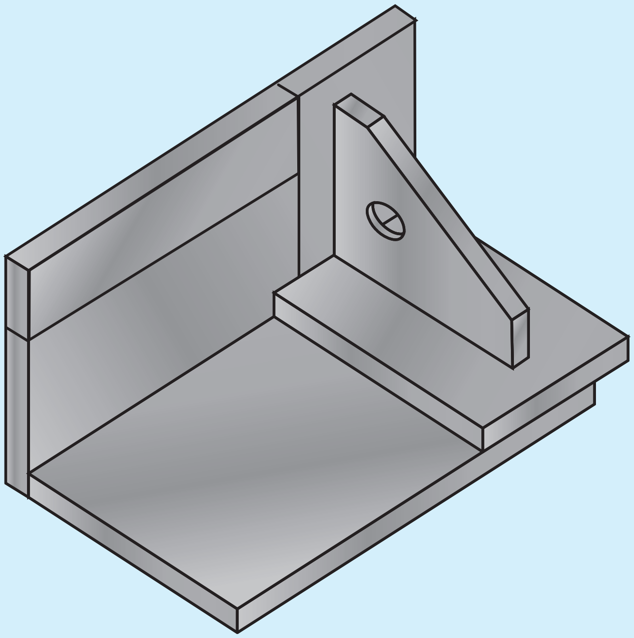


FIGURE 15-23 Practices 15-11 and 15-12 workmanship sample.

PRACTICE 15-12 AWS SENSE

AWS SENSE Entry-Level Welder Workmanship Sample for Flux Cored Arc Welding Self-Shielded (FCAW-S)

Welding Procedure Specification (WPS) No.: Practice 15-12.

Title:

Welding FCAW of plate to plate.

Scope:

This procedure is applicable for V-groove, bevel, and fillet welds within the range of 1/8 in. (3.2 mm) through 1 1/2 in. (38 mm) for the AWS SENSE Level I all-position groove and fillet welds using the FCAW-S welding process.

Welding may be performed in the following positions:

All.

Base Metal:

The base metal shall conform to carbon steel M-1, P-1, and S-1, Group 1 or 2.

Backing Material Specification:

None.

Filler Metal:

The filler metal shall conform to AWS specification no. 0.035 in. (0.90 mm) to 0.0415 in. (1.2 mm) diameter E71T-11 from AWS specification A5.20. This filler metal falls into F-number F-6 and A-number A-1.

Shielding Gas:

None.

Joint Design and Tolerances:

Refer to the drawing and specifications in Figure 15-22 for the workmanship sample layout.

Preparation of Base Metal:

The bevels are to be flame or plasma cut on the edges of the plate before the parts are assembled. The beveled surface must be smooth and free of notches. Any roughness or notches deeper than 1/64 in. (0.4 mm) must be ground smooth.

All hydrocarbons and other contaminants, such as cutting fluids, grease, oil, and primers, must be cleaned off all parts and filler metals before welding. This cleaning can be done with any suitable solvents or detergents. The groove face and inside and outside plate surfaces within 1 in. (25 mm) of the joint must be mechanically cleaned of slag, rust, and mill scale. Cleaning must be done with a wire brush or grinder down to bright metal.

Electrical Characteristics:

Set the voltage, amperage, and wire-feed speed flow according to Table 15-4.

Preheat:

The parts must be heated to a temperature higher than 50°F (10°C) before any welding is started.

Backing Gas:

N/A.

Safety:

Proper protective clothing and equipment must be used. The area must be free of all hazards that may affect the welder or others in the area. The welding machine, welding leads, work clamp, electrode holder, and other equipment must be in safe working order.

Welding Technique:

Using a 1/2-in. (13-mm) or larger gas nozzle and a distance from contact tube to work of approximately 3/4 in. (19 mm) for all welding, first tack weld the plates together according to Figure 15-22. There should be about a root gap of approximately 1/8 in. (3.2 mm) between the plates with V-grooved or beveled edges. Use an E71T-11 arc welding electrode to make a weld. If multiple pass welds are going to be made, then a root pass weld should be made to fuse the plates together. Clean the slag from the root pass, being sure to remove any trapped slag along the sides of the weld.

Using an E71T-11 arc welding electrode, make a series of stringer or weave filler welds, no thicker than 1/4 in. (6.4 mm) in the groove until the joint is filled. The 1/4-in. (6.4-mm) fillet welds are to be made with one pass.

Interpass Temperature:

The plate should not be heated to a temperature higher than 350°F (175°C) during the welding process. After each weld pass is completed, allow it to cool but never to a temperature below 50°F (10°C). The weldment must not be quenched in water.

Cleaning:

The slag must be cleaned off between passes. The weld beads may be cleaned by a hand wire brush, a chipping hammer, a punch, and hammer, or a needle scaler. All weld cleaning must be performed with the test plate in the welding position. A grinder may not be used to remove weld control problems such as undercut, overlap, or trapped slag.

Visual Inspection Criteria for Entry Welders:

There shall be no cracks and no incomplete fusion. There shall be no incomplete joint penetration in groove welds except as permitted for partial joint penetration welds.

The Test Supervisor shall examine the weld for acceptable appearance and shall be satisfied that the welder is skilled in using the process and procedure specified for the test.

Undercut shall not exceed the lesser of 10% of the base metal thickness or 1/32 in. (0.8 mm).

When visual examination is the only criterion for acceptance, all weld passes are subject to visual examination at the discretion of the Test Supervisor.

The frequency of porosity shall not exceed one in each 4 in. (100 mm) of weld length, and the maximum diameter shall not exceed 3/32 in. (2.4 mm).

Welds shall be free from overlap.

Sketches:

Flux Cored Arc Welding (FCAW) Self-Shielded Workmanship Sample drawing, Figure 15-23.

Paperwork:

Complete a "Bill of Materials," "Time Sheet," and "Performance Qualification Test Record" in Appendix I or as provided by your instructor. ◆

CAUTION

Anytime you are welding on fixed position pipe test samples, you must protect yourself from falling sparks and spatter by wearing all of the appropriate PPE to prevent accidental burns.

PRACTICE 15-13 AWS SENSE

Gas Metal Arc Welding—Short-Circuit Metal Transfer (GMAW-S) Workmanship Sample

Welding Procedure Specification (WPS) No.: Practice 15-13.

Title:

Welding GMAW-S of carbon steel plate to carbon steel plate.

Scope:

This procedure is applicable for square 2G and 5G groove on 4-in. to 6-in. (100 mm to 150 mm) schedule 40 carbon steel pipe with and without backing for the AWS SENSE Level II short-circuit metal transfer GMA pipe welding.

Welding may be performed in the following positions:

2G and *5G*

Base Metal:

The base metal shall conform to carbon steel M-1, P-1, and S-1, Group 1 or 2.

Backing Material Specification:

Backing metal shall conform to carbon steel M-1, P-1, and S-1, Group 1 or 2.

Filler Metal:

The filler metal shall conform to AWS specification no. E70S-X from AWS specification A5.18. This filler metal falls into F-number F-6 and A-number A-1.

Shielding Gas:

The shielding gas, or gases, shall conform to the following compositions and purity: 25% CO_2 + 75% Ar at 30 to 50 cfh or Ar + 2% to 5% O_2 at 30 to 50 cfh.

Joint Design and Tolerances:

Refer to the drawing in **Figure 15-24** for the joint layout specifications.

Preparation of Base Metal:

All parts may be mechanically cut or machine PAC unless specified as manual PAC.

All hydrocarbons and other contaminants, such as cutting fluids, grease, oil, and primers, must be cleaned off all parts and filler metals before welding. This cleaning can be done with any suitable solvents or detergents. The groove face and inside and outside plate surfaces within 1 in. (25 mm) of the joint must be mechanically cleaned of slag, rust, and mill scale. Cleaning must be done with a wire brush or grinder down to bright metal.

Electrical Characteristics:

Set the voltage, amperage, wire-feed speed, and shielding gas flow according to Table 15-1.

Preheat:

The parts must be heated to a temperature higher than 50°F (10°C) before any welding is started.

Backing Gas:

N/A.

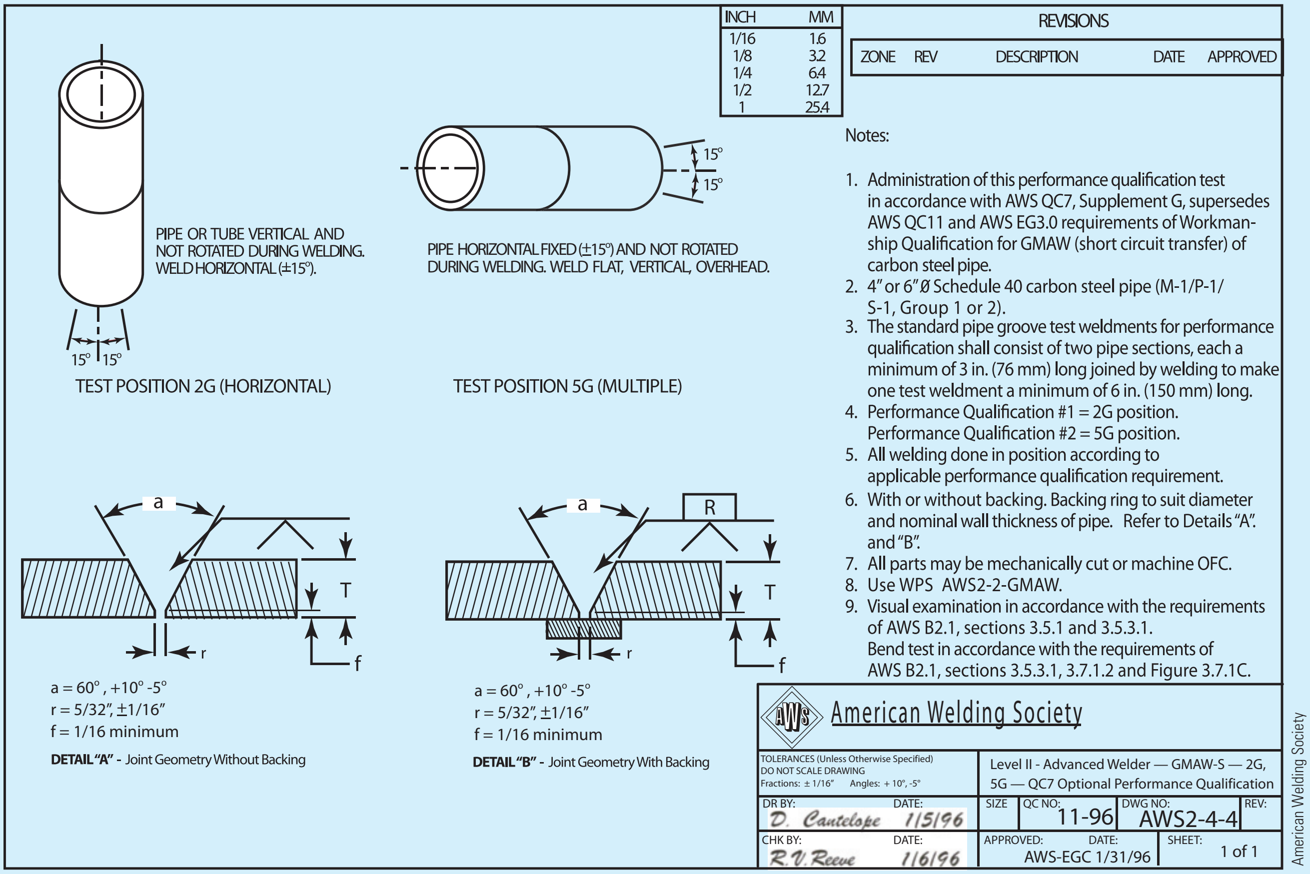


FIGURE 15-24 Practice 15-13 AWS SENSE GMAW Short-Circuit Metal Transfer Workmanship for carbon steel pipe.

Safety:

Proper protective clothing and equipment must be used. The area must be free of all hazards that may affect the welder or others in the area. The welding machine, welding leads, work clamp, electrode holder, and other equipment must be in safe working order.

Welding Technique:

Using a 1/2-in. (13-mm) or larger gas nozzle for all welding, first tack weld the plates together according to the drawing, Figure 15-24. Make four tack welds approximately 1 in. (25 mm) long. Grind the ends of the tack welds to a featheredge with a narrow grinding disk.

Use the E70S-X filler metal to fuse the plates together. Clean any silicon slag, being sure to remove any trapped silicon slag along the sides of the weld.

All welds are to be made with one pass. All welds must be placed in the orientation shown in the drawing.

Interpass Temperature:

The plate should not be heated to a temperature higher than 350°F (175°C) during the welding process. After each weld pass is completed, allow it to cool, but never to a temperature below 50°F (10°C). The weldment must not be quenched in water.

Cleaning:

The weld beads may be cleaned by a hand wire brush, a chipping hammer, a punch, hammer, and/or a narrow grinding disk. All weld cleaning must be performed with the test plate in the welding position.

Visual Inspection:

There shall be no cracks and no incomplete fusion. There shall be no incomplete joint penetration in groove welds except as permitted for partial joint penetration welds.

- The Test Supervisor shall examine the weld for acceptable appearance and shall be satisfied that the welder is skilled in using the process and procedure specified for the test.
- Undercut shall not exceed the lesser of 10% of the base metal thickness or 1/32 in. (0.8 mm).
- When visual examination is the only criterion for acceptance, all weld passes are subject to visual examination at the discretion of the Test Supervisor.
- The frequency of porosity shall not exceed one in each 4 in. (100 mm) of weld length, and the maximum diameter shall not exceed 3/32 in. (2.4 mm).
- Welds shall be free from overlap.

Bend Test:

The weld is to be mechanically tested only after it has passed the visual inspection. Be sure that the test specimens are properly marked to identify the welder, the position, and the process.

Specimen Preparation:

Four specimens are to be located in accordance with the requirements in **Figure 15-25**. Two are to be prepared for a transverse face bend, and the other two are to be prepared for a transverse root bend, **Figure 15-26**.

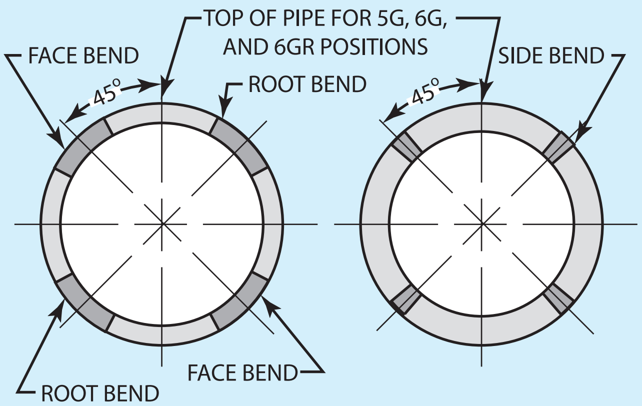
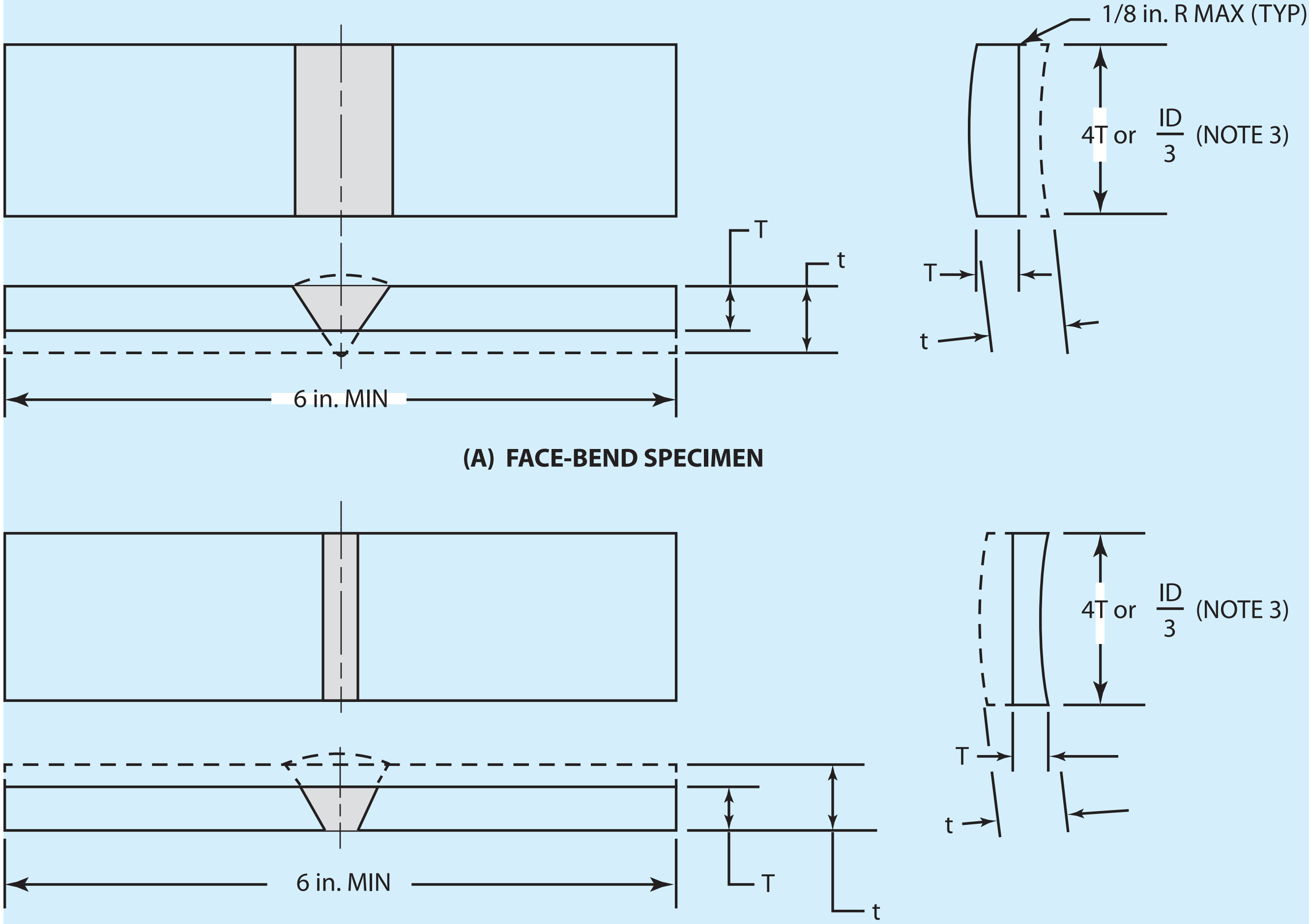


FIGURE 15-25 Location for pipe-bend test specimens.



(B) ROOT-BEND SPECIMEN

t	T
≤ 3/8 in.	t
> 3/8 in.	3/8 in.

in.	mm
1/8	3.0
3/8	9.5
6	152.2

FIGURE 15-26 Specimen preparation.

- *Transverse face bend.* The weld is perpendicular to the longitudinal axis of the specimen and is bent so that the weld face becomes the tension surface of the specimen.
- *Transverse root bend.* The weld is perpendicular to the longitudinal axis of the specimen and is bent so that the weld root becomes the tension surface of the specimen.

Acceptance Criteria for Bend Test:

For acceptance, the convex surface of the face and root bend specimens shall meet both of the following requirements:

- No single indication shall exceed 1/8 in. (3.2 mm) measured in any direction on the surface.
- The sum of the greatest dimensions of all indications on the surface that exceed 1/32 in. (0.8 mm) but are less than or equal to 1/8 in. (3.2 mm) shall not exceed 3/8 in. (9.5 mm).

Sketches:

GMAW Short-Circuit Metal Transfer Workmanship Sample drawing, **Figure 15-27**.

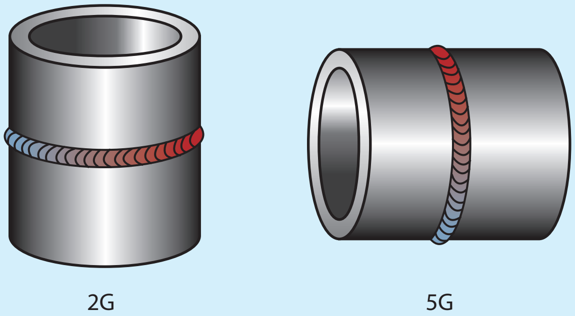


FIGURE 15-27 2G and 5G pipe positions.

Paperwork:

Complete a "Bill of Materials," "Time Sheet," and "Performance Qualification Test Record" in Appendix I or as provided by your instructor. ◆

PRACTICE 15-14 AWS SENSE

AWS SENSE Entry-Level Welder Workmanship Sample for Flux Cored Arc Welding, Gas-Shielded (FCAW-G)

Welding Procedure Specification (WPS) No.: Practice 15-14.

Title:

Welding FCAW of plate to plate.

Scope:

This procedure is applicable for square 2G and 5G groove on 6-in. to 8-in. (150 mm to 200 mm) schedule 40 carbon steel pipe with and without backing for the AWS SENSE Level II short-circuit metal transfer FCAW-G pipe welding.

Welding may be performed in the following positions:

All.

Base Metal:

The base metal shall conform to carbon steel M-1, P-1, and S-1, Group 1 or 2.

Backing Material Specification:

None.

Filler Metal:

The filler metal shall conform to AWS specification no. E71T-1 from AWS specification A5.20. This filler metal falls into F-number F-6 and A-number A-1.

Shielding Gas:

The shielding gas, or gases, shall conform to the following compositions and purity: 25% CO_2 + 75% Ar at 30 to 50 cfh.

Joint Design and Tolerances:

Refer to the drawing and specifications in **Figure 15-28** for the workmanship sample layout.

Preparation of Base Metal:

The bevels are to be flame or plasma cut on the edges of the plate before the parts are assembled. The beveled surface must be smooth and free of notches. Any roughness or notches deeper than 1/64 in. (0.4 mm) must be ground smooth.

All hydrocarbons and other contaminants, such as cutting fluids, grease, oil, and primers, must be cleaned off all parts and filler metals before welding. This cleaning can be done with any suitable solvents or detergents. The groove face and inside and outside plate surfaces within 1 in. (25 mm) of the joint must be mechanically cleaned of slag, rust, and mill scale. Cleaning must be done with a wire brush or grinder down to bright metal.

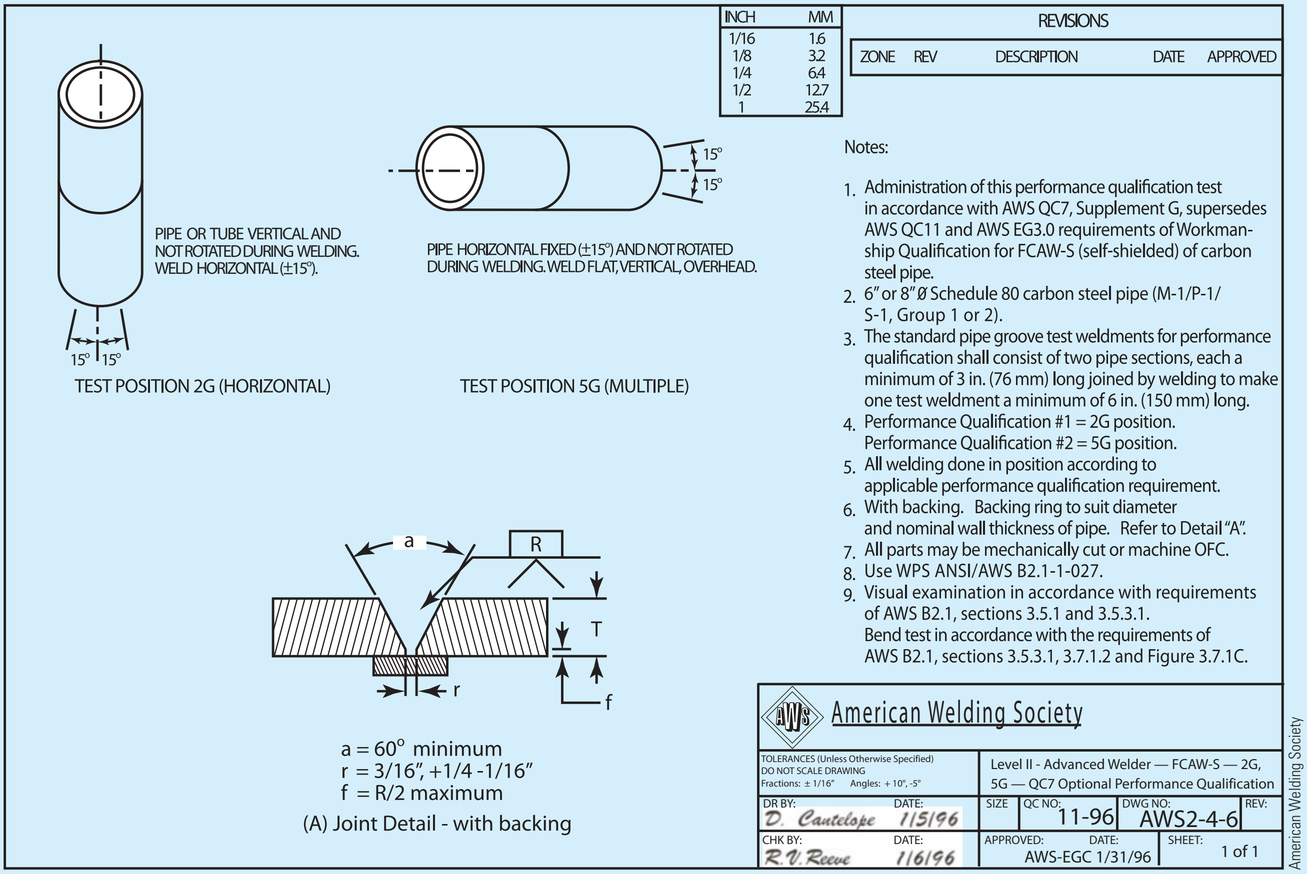


FIGURE 15-28 Practices 15-11 and 15-12 AWS SENSE Flux Cored Arc Welding FCAW-G and FCAW-S Workmanship sample for steel pipe.

Electrical Characteristics:

Set the voltage, amperage, wire-feed speed, and shielding gas flow according to Table 15-3.

Preheat:

The parts must be heated to a temperature higher than 50°F (10°C) before any welding is started.

Backing Gas:

N/A.

Safety:

Proper protective clothing and equipment must be used. The area must be free of all hazards that may affect the welder or others in the area. The welding machine, welding leads, work clamp, electrode holder, and other equipment must be in safe working order.

Welding Technique:

Using a 1/2-in. (13-mm) or larger gas nozzle and a distance from contact tube to work of approximately 3/4 in. (19 mm) for all welding, first tack weld the plates together according to Figure 15-28. There should be a root gap of approximately 1/8 in. (3.2 mm) between the plates with V-grooved or beveled edges. Use an E71T-1 arc welding electrode to make a weld. If multiple pass welds are going to be made, then a root pass weld should be made to fuse the plates together. Clean the slag from the root pass, being sure to remove any trapped slag along the sides of the weld.

Using an E71T-1 arc welding electrode, make a series of stringer or weave filler welds no thicker than 1/4 in. (6.4 mm) in the groove until the joint is filled. The 1/4-in. (6.4-mm) fillet welds are to be made with one pass.

Interpass Temperature:

The plate should not be heated to a temperature higher than 350°F (175°C) during the welding process. After each weld pass is completed, allow it to cool, but never to a temperature below 50°F (10°C). The weldment must not be quenched in water.

Cleaning:

The slag must be cleaned off between passes. The weld beads may be cleaned by a hand wire brush, a chipping hammer, a punch, and hammer, or a needle scaler. All weld cleaning must be performed with the test plate in the welding position. A grinder may not be used to remove weld control problems such as undercut, overlap, or trapped slag.

Visual Inspection:

There shall be no cracks and no incomplete fusion. There shall be no incomplete joint penetration in groove welds except as permitted for partial joint penetration welds.

- The Test Supervisor shall examine the weld for acceptable appearance and shall be satisfied that the welder is skilled in using the process and procedure specified for the test.
- Undercut shall not exceed the lesser of 10% of the base metal thickness or 1/32 in. (0.8 mm).
- When visual examination is the only criterion for acceptance, all weld passes are subject to visual examination at the discretion of the Test Supervisor.
- The frequency of porosity shall not exceed one in each 4 in. (100 mm) of weld length, and the maximum diameter shall not exceed 3/32 in. (2.4 mm).
- Welds shall be free from overlap.

Bend Test:

The weld is to be mechanically tested only after it has passed the visual inspection. Be sure that the test specimens are properly marked to identify the welder, the position, and the process.

Specimen Preparation:

Four specimens are to be located in accordance with the requirements in Figure 15-25. Two are to be prepared for a transverse face bend, and the other two are to be prepared for a transverse root bend, Figure 15-26.

- *Transverse face bend.* The weld is perpendicular to the longitudinal axis of the specimen and is bent so that the weld face becomes the tension surface of the specimen.
- *Transverse root bend.* The weld is perpendicular to the longitudinal axis of the specimen and is bent so that the weld root becomes the tension surface of the specimen.

Acceptance Criteria for Bend Test:

For acceptance, the convex surface of the face and root bend specimens shall meet both of the following requirements:

- No single indication shall exceed 1/8 in. (3.2 mm) measured in any direction on the surface.
- The sum of the greatest dimensions of all indications on the surface that exceed 1/32 in. (0.8 mm) but are less than or equal to 1/8 in. (3.2 mm) shall not exceed 3/8 in. (9.5 mm).

Sketches:

Flux Cored Arc Welding (FCAW) Gas Shielded Workmanship Sample drawing, Figure 15-27.

Paperwork:

Complete a "Bill of Materials," "Time Sheet," and "Performance Qualification Test Record" in Appendix I or as provided by your instructor. ◆

PRACTICE 15-15 AWS SENSE

AWS SENSE Entry-Level Welder Workmanship Sample for Flux Cored Arc Welding Self-Shielded (FCAW-S)

Welding Procedure Specification (WPS) No.: Practice 15-15.

Title:

Welding FCAW of plate to plate.

Scope:

This procedure is applicable for square 2G and 5G groove on 6-in. to 8-in. (150 mm to 200 mm) schedule 40 carbon steel pipe with and without backing for the AWS SENSE Level II short-circuit metal transfer FCAW-S pipe welding.

Welding may be performed in the following positions:

All.

Base Metal:

The base metal shall conform to carbon steel M-1, P-1, and S-1, Group 1 or 2.

Backing Material Specification:

None.

Filler Metal:

The filler metal shall conform to AWS specification no. 0.035 in. (0.90 mm) to 0.0415 in. (1.2 mm) diameter E71T-11 from AWS specification A5.20. This filler metal falls into F-number F-6 and A-number A-1.

Shielding Gas:

None.

Joint Design and Tolerances:

Refer to the drawing and specifications in Figure 15-28 for the workmanship sample layout.

Preparation of Base Metal:

The bevels are to be flame or plasma cut on the edges of the plate before the parts are assembled. The beveled surface must be smooth and free of notches. Any roughness or notches deeper than 1/64 in. (0.4 mm) must be ground smooth.

All hydrocarbons and other contaminants, such as cutting fluids, grease, oil, and primers, must be cleaned off all parts and filler metals before welding. This cleaning can be done with any suitable solvents or detergents. The groove face and inside and outside plate surfaces within 1 in. (25 mm) of the joint must be mechanically cleaned of slag, rust, and mill scale. Cleaning must be done with a wire brush or grinder down to bright metal.

Electrical Characteristics:

Set the voltage, amperage, and wire-feed speed flow according to Table 15-4.

Preheat:

The parts must be heated to a temperature higher than 50°F (10°C) before any welding is started.

Backing Gas:

N/A.

Safety:

Proper protective clothing and equipment must be used. The area must be free of all hazards that may affect the welder or others in the area. The welding machine, welding leads, work clamp, electrode holder, and other equipment must be in safe working order.

Welding Technique:

Using a 1/2-in. (13-mm) or larger gas nozzle and a distance from contact tube to work of approximately 3/4 in. (19 mm) for all welding, first tack weld the plates together according to Figure 15-28. There should be a root gap of approximately 1/8 in. (3.2 mm) between the plates with V-grooved or beveled edges. Use an E71T-11 arc welding electrode to make

a weld. If multiple pass welds are going to be made, then a root pass weld should be made to fuse the plates together. Clean the slag from the root pass, being sure to remove any trapped slag along the sides of the weld.

Using an E71T-11 arc welding electrode, make a series of stringer or weave filler welds no thicker than 1/4 in. (6.4 mm) in the groove until the joint is filled. The 1/4-in. (6.4-mm) fillet welds are to be made with one pass.

Interpass Temperature:

The plate should not be heated to a temperature higher than 350°F (175°C) during the welding process. After each weld pass is completed, allow it to cool, but never to a temperature below 50°F (10°C). The weldment must not be quenched in water.

Cleaning:

The slag must be cleaned off between passes. The weld beads may be cleaned by a hand wire brush, a chipping hammer, a punch, and hammer, or a needle scaler. All weld cleaning must be performed with the test plate in the welding position. A grinder may not be used to remove weld control problems such as undercut, overlap, or trapped slag.

Visual Inspection Criteria for Entry Welders:

There shall be no cracks and no incomplete fusion. There shall be no incomplete joint penetration in groove welds except as permitted for partial joint penetration welds.

The Test Supervisor shall examine the weld for acceptable appearance and shall be satisfied that the welder is skilled in using the process and procedure specified for the test.

Undercut shall not exceed the lesser of 10% of the base metal thickness or 1/32 in. (0.8 mm).

Where visual examination is the only criterion for acceptance, all weld passes are subject to visual examination at the discretion of the Test Supervisor.

The frequency of porosity shall not exceed one in each 4 in. (100 mm) of weld length, and the maximum diameter shall not exceed 3/32 in. (2.4 mm).

Welds shall be free from overlap.

Bend Test:

The weld is to be mechanically tested only after it has passed the visual inspection. Be sure that the test specimens are properly marked to identify the welder, the position, and the process.

Specimen Preparation:

For 3/8-in. (9.5-mm) test plates, two specimens are to be located in accordance with the requirements in Figure 15-25. One is to be prepared for a transverse face bend, and the other is to be prepared for a transverse root bend, Figure 15-26.

- *Transverse face bend.* The weld is perpendicular to the longitudinal axis of the specimen and is bent so that the weld face becomes the tension surface of the specimen.
- *Transverse root bend.* The weld is perpendicular to the longitudinal axis of the specimen and is bent so that the weld root becomes the tension surface of the specimen.

Acceptance Criteria for Bend Test:

For acceptance, the convex surface of the face and root bend specimens shall meet both of the following requirements:

- No single indication shall exceed 1/8 in. (3.2 mm) measured in any direction on the surface.
- The sum of the greatest dimensions of all indications on the surface that exceed 1/32 in. (0.8 mm) but are less than or equal to 1/8 in. (3.2 mm) shall not exceed 3/8 in. (9.5 mm).

Sketches:

Flux Cored Arc Welding (FCAW) Self-Shielded Workmanship Sample drawing, Figure 15-27.

Paperwork:

Complete a "Bill of Materials," "Time Sheet," and "Performance Qualification Test Record" in Appendix I or as provided by your instructor.

Summary

Successfully completing an AWS SENSE qualification workmanship standard is a significant accomplishment for any welder. It represents a level of skill that meets the requirements for many welding jobs. It is an accomplishment that you should be proud of and a fact that you should include on any job application.

Review

1. How are the sheet steel workmanship samples tested in Practice 15-1?
2. What size are the fillet welds in Practice 15-2?
3. How should the welds be cleaned on workmanship samples?
4. What is the acceptable undercut on workmanship samples?
5. In Practice 15-3, what size should the root face be?
6. How wide of an area should be cleaned on the plate surface before welding?
7. What is the root opening for the butt joints in Practice 15-5?
8. How is the 1 in. diameter hole cut in the workmanship sample in Practice 15-5?
9. According to Figure 15-15, how are the test specimens bent?
10. According to Practice 15-6, after each weld pass the test plate should be allowed to cool but never allowed to cool below what temperature?
11. What is the bevel angle for the test plates in Practice 15-7?
12. What type of groove is required for 2G butt welds?
13. What weave pattern is used for the cover pass on 2G groove butt joint welds?
14. How can slag be cleaned off of FCAW-G and FCAW-S welds?
15. What types of welds are used on lap and tee joints?
16. What shielding gas mixture and flow rate are recommended for the FCAW-G SENSE workmanship samples?
17. What is the maximum interpass temperature for Practice 15-11?
18. What is the maximum allowable undercut for a visual inspection of a weld?
19. What shielding gas mixture and flow rate are recommended for the GMAW-S SENSE pipe workmanship samples?
20. What are the maximum acceptance criteria for bend test specimens?
21. According to Table 15-4, what is the range of volts and amps for E70T-11 0.035 diameter filler wire?

Chapter 16

Gas Tungsten Arc Welding Equipment, Setup, Operation, and Filler Metals

OBJECTIVES

After completing this chapter, the student should be able to

- describe the gas tungsten arc welding process and list the other terms used to describe it.
- explain what makes tungsten a good electrode.
- tell how tungsten erosion can be limited.
- discuss how the various types of tungsten electrodes are used.
- tell how to shape the end of the tungsten electrode and how to clean it.
- demonstrate how to grind a point on a tungsten electrode using an electric grinder.
- demonstrate how to remove a contaminated tungsten end.
- demonstrate how to melt the end of the tungsten electrode into the desired shape.
- compare water-cooled GTA welding torches to air-cooled torches.
- tell the purposes of the three hoses connecting a water-cooled torch to the welding machine.
- discuss how to choose an appropriate nozzle for the job.
- tell what procedures must be followed to get an accurate reading on a flowmeter.
- compare the three types of welding current used for GTA welding.
- discuss the shielding gases used in the GTA welding process.
- define *preflow* and *postflow*.
- explain the problems that can occur as a result of an incorrect gas flow rate.
- demonstrate how to properly set up a GTA welder.
- demonstrate how to establish a GTA welding arc.

KEY TERMS

cleaning action
collet
flowmeter
frequency
inert gas
noble inert gases
postflow
preflow
tungsten

INTRODUCTION

The gas tungsten arc welding (GTAW) process is sometimes referred to as TIG, or heliarc. The term *TIG* is short for tungsten inert gas welding, and the much older term *heliarc* was used because helium was the first gas used for the process. The aircraft manufacturer, Northrop Aircraft, developed the GTAW process for welding an all-magnesium aircraft, XP-56 Black Bullet, during the late 1930s. Helium, an inert gas, was used as the shielding gas, along with DCEP welding current and a tungsten or carbon electrode. The carbon electrodes caused many problems and were quickly discontinued. In the mid-1940s, improvements in gas composition and a better understanding of the importance of polarity improved the effectiveness of the process and reduced its cost.

To use this process, an arc is established between a nonconsumable tungsten electrode and the base metal, which is called the work. Under the correct welding conditions, the electrode does not melt, although the work does at the spot where the arc impacts its surface and produces a molten weld pool. The filler metal is thin wire that is fed directly into the molten weld pool where it melts. Because hot tungsten is sensitive to oxygen contamination, a good inert shielding gas is required to keep the air away from the hot tungsten and molten weld metal. The **inert gas** provides the needed arc characteristics and protects the molten weld pool. Because fluxes are not used, the welds produced are sound, free of slags, and as corrosion-resistant as the parent metal.

Before development of the GTAW process, welding aluminum and magnesium was difficult. The welds produced were porous and prone to corrosion.

When argon became plentiful and DCEN was recognized as more suitable than DCEP, the GTA process became more common. Until the development of GMAW in the late 1940s, GTAW was the only acceptable process for welding reactive materials such as aluminum, magnesium, titanium, and some grades of stainless steel, regardless of thickness. Reactive metals are ones that are easily contaminated when heated to their molten welding temperatures. Contamination can come from the air or be picked up from the surfaces such as oxides, oils, paints, or similar materials. Although economical for welding sheet metal, the process proved tedious and expensive for joining sections much thicker than 1/4 in. (6 mm). The eye–hand coordination required to make GTA welds is very similar to the coordination required for oxyfuel gas welding.

TUNGSTEN

Tungsten, atomic symbol W, has the following properties:

- High tensile strength: 500,000 lb/in.^{2} (3447 kg/mm^2)
- Hardness, Rockwell C45
- High melting temperature: 6170°F (3410°C)
- High boiling temperature: 10,700°F (5630°C)
- Good electrical conductivity

Tungsten is produced mainly by reduction of its trioxide with hydrogen. Powdered tungsten is then purified to 99.95+%, compressed, and sintered (heated to a temperature below melting where grain growth can occur) to make an ingot. The ingot is heated to increase ductility and then is swaged and drawn through dies to produce electrodes. These electrodes are available in sizes varying from 0.01 in. to 0.25 in. (0.25 mm to 6.4 mm) in diameter. The tungsten electrode, after drawing, has a heavy black oxide that is later chemically cleaned or ground off.

High Temperature

The high melting temperature and good electrical conductivity make tungsten the best choice for a nonconsumable electrode. The arc temperature, approximately 11,000°F (6000°C), is much higher than the melting temperature of tungsten but not much higher than its boiling temperature of 10,600°F (5900°C).

As the tungsten electrode becomes hot, the arc between the electrode and the work will stabilize. Because electrons are more freely emitted from hot tungsten, the very highest temperature possible at the tungsten electrode tip is desired. Maintaining a balance between the heat required to have a stable arc and that high enough to melt the tungsten requires an understanding of the GTA torch and electrode.

Good Conductor

The thermal conductivity of tungsten and the heat input are prime factors in the use of tungsten as an electrode. In general, tungsten is a good conductor of heat. This conductive property is what allows the tungsten electrode to withstand the arc temperature well above its melting temperature. The heat of the arc is conducted away from the electrode's end so fast that it does not reach its melting temperature. For example, a wooden match burns at approximately 3000°F (1647°C). Because aluminum melts at 1220°F (971°C), a match should easily melt an aluminum wire. However, a match will not even melt a 1/16-in. (2-mm) aluminum wire. The aluminum, like a tungsten electrode, conducts the heat away so quickly that it will not melt.

Tungsten Erosion

Because of the intense heat of the arc, some erosion of the electrode will occur. This eroded metal is transferred across the arc, **Figure 16-1**. Slow erosion of the electrode results in limited tungsten inclusions in the weld, which are acceptable. Standard codes give the size and amount of tungsten inclusions that are allowable in various types

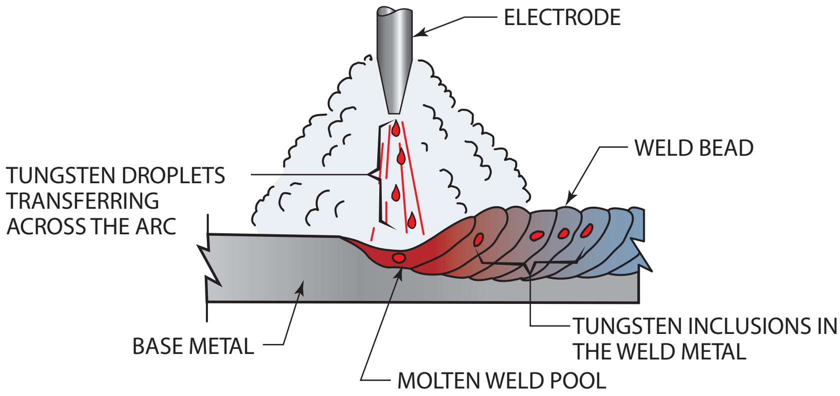


FIGURE 16-1 Some tungsten will erode from the electrode, be transferred across the arc, and become trapped in the weld deposit.

of welds. The tungsten inclusions are hard spots that cause stresses to concentrate, possibly resulting in weld failure. Although tungsten erosion cannot be completely eliminated, it can be controlled. A few ways of limiting erosion include:

- using ground tungsten to lower the tungsten tip's temperature by having a good mechanical, electrical, and thermal contact between the electrode and the collet,
- using as low of a current as possible,
- using a water-cooled torch,
- using as large of a size of tungsten electrode as possible,
- using DCEN current or a balanced wave AC current,
- using as short of an electrode extension from the collet as possible,
- using the proper electrode end shape, and
- using an alloyed tungsten electrode.

The torch end of the electrode is tightly clamped in a collet. The collet inside the torch is cooled by air or water. The **collet** is the cone-shaped sleeve that holds the electrode in the torch. Heat from both the arc and the tungsten electrode's resistance to the flow of current must be absorbed by the collet and torch. To ensure that the electrode is being cooled properly, be sure the collet connection is clean and tight. For water-cooled torches, make sure water flow is adequate.

The somewhat uneven surface of a cleaned tungsten electrode results in higher electrical resistance between the tungsten and collet. The higher resistance increases the tungsten's temperature resulting in more tungsten erosion. For that reason, most codes require that only ground tungsten be used for all GTA welding, **Figure 16-2** and **Figure 16-3**.

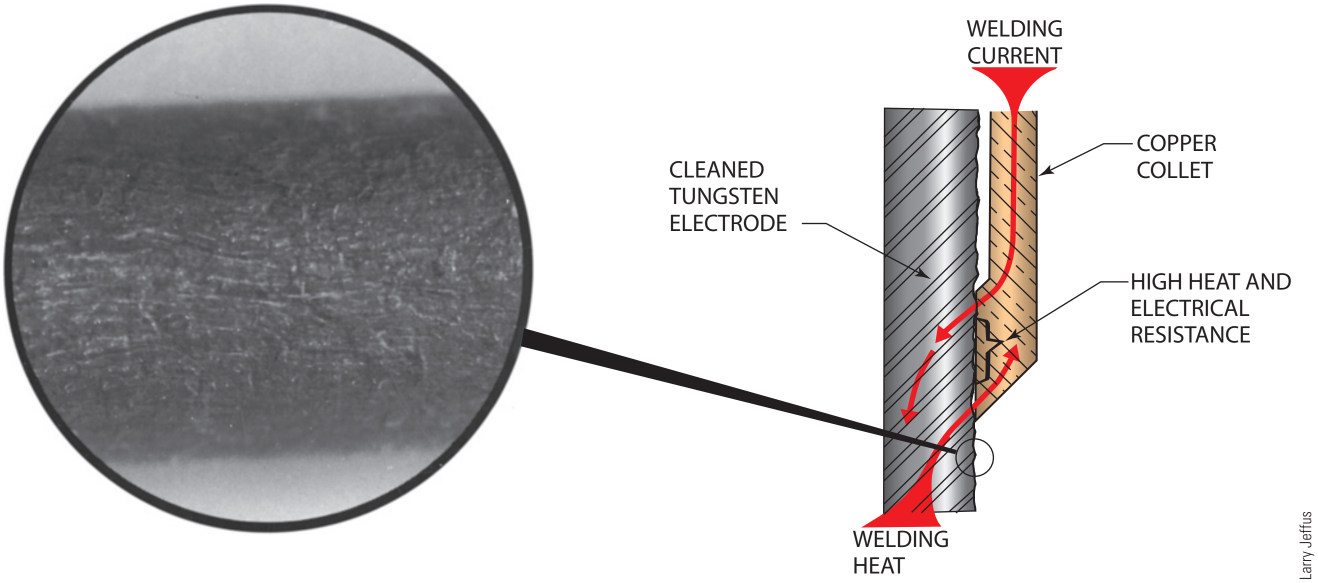


FIGURE 16-2 Irregular surface of a cleaned tungsten electrode (poor heat transfer to collet).

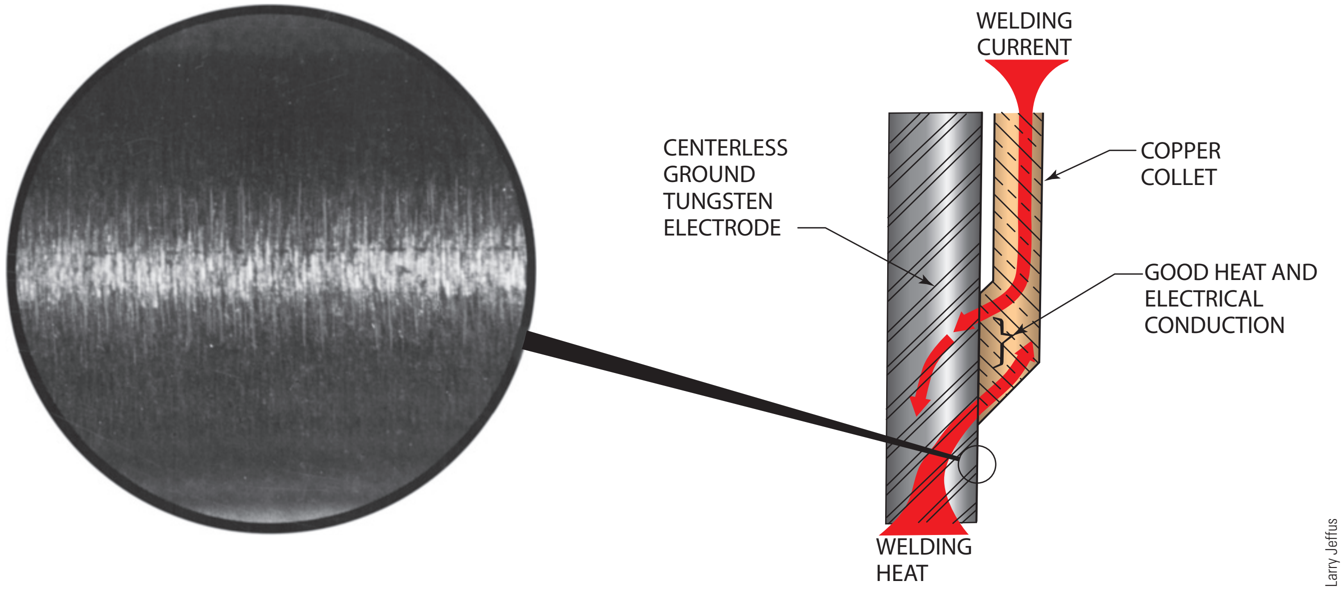


FIGURE 16-3 Smooth surface of a centerless ground tungsten electrode (good heat transfer to collet).

Large-diameter electrodes conduct more current because the resistance heating effects are reduced. However, excessively large sizes may result in too low of a temperature for a stable arc.

Tungsten Electrode End Shape

The preferred electrode tip shape impacts the temperature and erosion of the tungsten.

DCEN Tungsten End Shape With DCEN, a pointed tip concentrates the arc as much as possible and improves arc-starting with either a high-voltage electrical discharge or a touch start. Because DCEN does not put much heat on the tip, it is relatively cool, the point is stable, and it can survive extensive use without damage, **Figure 16-4A.**

AC Tungsten End Shape With conventional alternating current (AC), the tip is subjected to more heat than with DCEN. To allow a larger mass at the tip to withstand the higher heat, the tip is rounded. The melted end must be small to ensure the best arc stability, **Figure 16-4B**. However, with electronically controlled balanced wave AC welding machines, the heat on the tungsten can be better controlled. So, with these newer welding machines, pointed tungsten with a small blunted end works well.

DCEP Tungsten End Shape DCEP has the highest heat concentration on the electrode tip. For this reason a slight ball of molten tungsten is suspended at the end of a tapered electrode tip. The liquid tungsten surface tension with the larger mass above the molten ball holds it in place like a drop of water on your fingertip, **Figure 16-4C**.

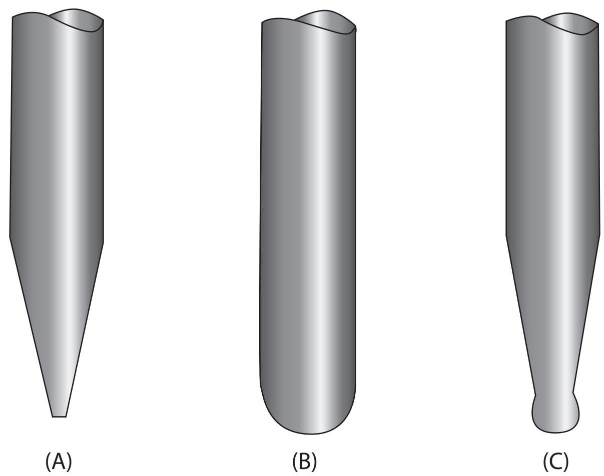


FIGURE 16-4 Basic tungsten electrode and shapes: pointed (A), rounded (B), and tapered with a balled end (C).

TYPES OF TUNGSTEN ELECTRODES

Pure tungsten has a number of properties that make it an excellent nonconsumable electrode for the GTA welding process. These properties can be improved by adding cerium, lanthanum, thorium, or zirconium to the tungsten.

For GTA welding, tungsten electrodes are classified as the following:

- Pure tungsten, EWP
- 1% thorium tungsten, EWTh-1
- 2% thorium tungsten, EWTh-2
- 1/4% to 1/2% zirconium tungsten, EWZr
- 2% cerium tungsten, EWCe-2

AWS Classification	Tungsten Composition	Tip Color
EWP	Pure tungsten	Green
EWTh-1	1% thorium added	Yellow
EWTh-2	2% thorium added	Red
EWZr	1/4% to 1/2% zirconium added	Brown
EWCe-2	2% cerium added	Orange
EWLa-1	1% lanthanum added	Black
EWG	Alloy not specified	Not specified

TABLE 16-1 Tungsten Electrode Types and Identification

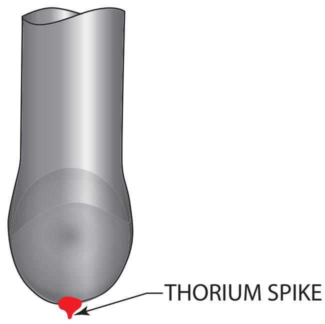


FIGURE 16-5 Thorium spike on a balled end tungsten electrode.

- 1% lanthanum tungsten, EWLa-1
- 1.5% lanthanum tungsten, EWLa-1.5
- 2% lanthanum tungsten, EWLa-2
- Alloy not specified, EWG

See **Table 16-1**.

More information on composition and other requirements for tungsten welding electrodes is available in the AWS publication A5.12, *Specifications for Tungsten and Tungsten Alloy Electrodes for Arc Welding and Cutting.*

Pure Tungsten, EWP

Pure tungsten has the poorest heat resistance and highest erosion rate and electron emission characteristics of all the tungsten electrodes. It can be used with AC welding of metals, such as aluminum and magnesium, because it easily forms a balled tip for good arc stability, especially with balanced wave welding power.

Thoriated Tungsten, EWTh-1 and EWTh-2

Thorium oxide (ThO_2), when added in percentages of up to 0.6% to tungsten, improves its current-carrying capacity. The addition of 1% to 2% of thorium oxide does not further improve current-carrying capacities. It does, however, help with electron emission. This can be observed by a reduction in the electron force (voltage) required to maintain an arc of a specific length. Thorium also increases the serviceable life of the tungsten. The improved electron emission of the thoriated tungsten allows it to carry approximately 20% more current. This also results in a corresponding reduction in electrode tip temperature, resulting in less tungsten erosion and subsequent weld contamination.

Thoriated tungstens also provide a much easier arc-starting characteristic than pure or zirconiated tungsten. Thoriated tungstens work well with DCEN. They can maintain a sharpened point well. They are very well suited for making welds on steel, steel alloys (including stainless), nickel alloys, and most other metals other than aluminum or magnesium.

Thoriated tungsten does not work well with alternating current (AC). It is difficult to maintain a balled end, which is required for AC welding. A thorium spike, **Figure 16-5**, may also develop on the balled end, disrupting a smooth arc.

CAUTION

Thorium is a very low-level radioactive oxide, but the level of radioactive contamination from a thorium electrode has not been found to be a health hazard during welding. It is, however, recommended that grinding dust be contained. Because of concern in other countries regarding radioactive contamination to the welder and welding environment, thoriated tungstens have been replaced with other alloys.

Zirconium Tungsten, EWZr-1

Zirconium oxide (ZrO_2) also helps tungsten emit electrons freely. The addition of zirconium to the tungsten has the same effect on the electrode characteristic as thorium, but to a lesser degree. Because of the difficulty in forming the desired balled end on thorium versus zirconium tungstens, zirconium is normally the electrode chosen for AC welding of aluminum and magnesium alloys. Zirconiated tungstens are more resistant to weld pool contamination than pure tungsten, thus providing excellent weld qualities with minimal contamination.

Zirconiated tungstens also have the advantage over thoriated tungsten in that they are not radioactive.

Cerium Tungsten, EWCe-2

Cerium oxide (CeO_2) is added to tungsten to improve the current-carrying capacity in the same manner as does thorium. These electrodes were developed as replacements for thoriated tungstens because they are not made of a radioactive material. Cerium oxide electrodes have a low arc-starting characteristic for improved arc-starting and arc stability at low current levels. This makes them well suited for welding on thin sections. They can also provide a longer life than most other electrodes if they are not used on high amperage settings.

Cerium tungsten electrodes work best on DC but can be used on AC welding current. Cerium electrodes contain between 1.8% and 2.2% of cerium oxide.

Lanthanum Tungsten, EWLa-1.5

Lanthanum oxide (La_2O_3) between 1.3% and 1.7% is added to tungsten. Lanthanum oxide tungstens are not radioactive. They have current-carrying characteristics similar to those of the thorium tungsten and an excellent arc-starting characteristic. Because of the performance similarities in lanthanum electrodes to those of thorium electrodes, lanthanum electrodes can often be substituted for thorium electrodes without having to requalify the welding procedure.

An advantage that lanthanum offers is that it will hold a point for DC welding on stainless and mild steels and can be balled for AC welding on aluminum and magnesium. Lanthanum substantially increases the current-carrying capacity of the tungsten by 50% over pure tungsten.

Rare Earth Tungsten, EWG

The EWG classifications are a mixture of rare earth oxides, such as cerium, lanthanum, yttrium, and others, combined with approximately 97% of tungsten to form these electrodes. They can be used on AC and DC welding current for welding on alloyed steels, stainless steel, aluminum, copper, magnesium, and titanium. Because of their high current-carrying capacity they will operate at a lower tungsten temperature, thus reducing tungsten erosion.

SHAPING THE TUNGSTEN

The desired end shape of tungsten can be obtained by grinding, breaking, or remelting the end, or using chemical compounds. Tungsten is brittle and easily broken. Welders must be sure to make a smooth, square break where they want it to be located.

Precision Machine Tungsten Grinder

Most manufacturers have changed over to machines that are specifically designed for grinding tungsten electrodes, **Figure 16-6**. There are a number of advantages of using these tungsten-grinding machines:

- Often these machines have a dust extraction system as part of the machine.
- The precise angle required by the welding specification can be set.
- The grinding marks will always run in the correct direction.
- The flat end of the tapered tip can be accurately produced.
- The accurate repeatability of the tip geometry is important for most critical code quality welds.

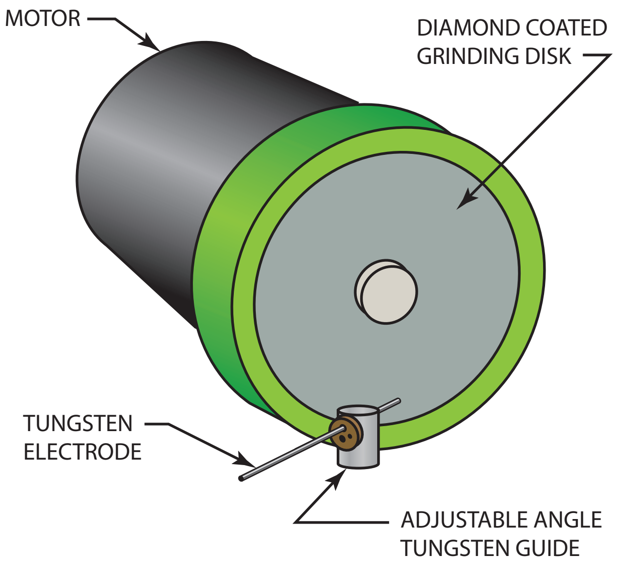


FIGURE 16-6 Typical tungsten sharpening tool.

- Tungsten as short as 1/2 in. (13 mm) can be safely sharpened.
- Safer and more accurate to use even for new welders.

NOTE

Lanthanated tungsten electrodes do not break evenly; they often split when you try to break off contamination. The contamination has to be removed before the tungsten is sharpened in most precision tungsten grinding machines. The two best ways of removing the contamination are to ground off or cut off by using a bench grinder.

Hand Grinding

Even though precision machine grinding of tungsten is preferred, you still need to be able to use a bench grinder to clean a contaminated tungsten or to point the end of a tungsten. The grinder used to sharpen tungsten should have a fine, hard stone. It should be used for grinding tungsten only. Because of the hardness of the tungsten and its brittleness, the grinding stone chips off small particles of the electrode. A coarse grinding stone will result in more tungsten breakage and a poorer finish. If the grinder is used for metals other than tungsten, then particles of these metals may become trapped on the tungsten as it is ground. The metal particles will quickly break free when the arc is started, resulting in weld contamination.

EXPERIMENT 16-1

Hand Grinding the Tungsten to the Desired Shape

Using an electric grinder with a fine grinding stone, one piece of tungsten 2 in. (51 mm) long or longer, and safety glasses, you will grind a point on the tungsten electrode.

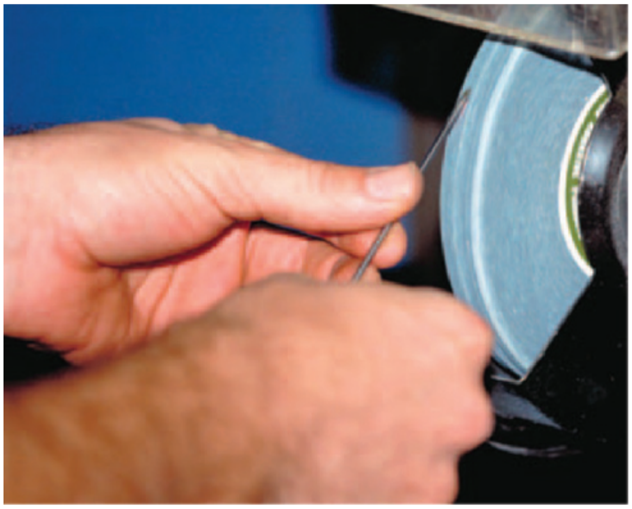
Because of the hardness of the tungsten, it will become hot. Its high thermal conductivity means that the heat will

be transmitted quickly to your fingers. To prevent overheating, only light pressure should be applied against the grinding wheel. This will also reduce the possibility of accidentally breaking the tungsten. Grind the tungsten so that the grinding marks run lengthwise, **Figure 16-7** and **Figure 16-8**. Lengthwise grinding reduces the amount of small particles of tungsten contaminating the weld. Move the tungsten up and down as it is twisted during grinding. This will prevent the tungsten from becoming hollow-ground.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

CAUTION

When holding one end of the tungsten against the grinding wheel, the other end of the tungsten must not be directed toward the palm of your hand, Figure 16-9. This will prevent the tungsten from being stuck into your hand if the grinding wheel catches it and suddenly pushes it downward.



Larry Jeffus

FIGURE 16-7 Correct method of grinding a tungsten electrode.

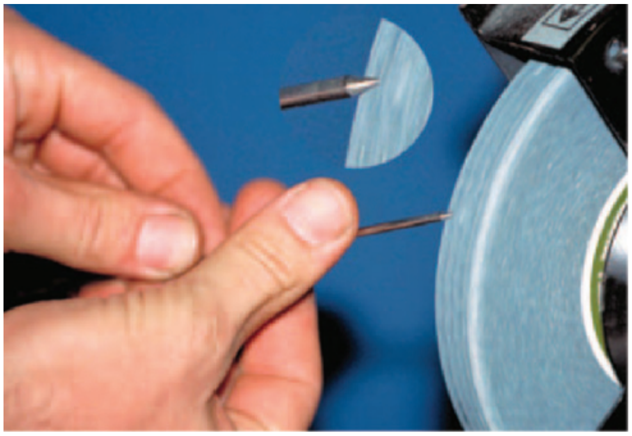


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FIGURE 16-8 Incorrect method of grinding a tungsten electrode.

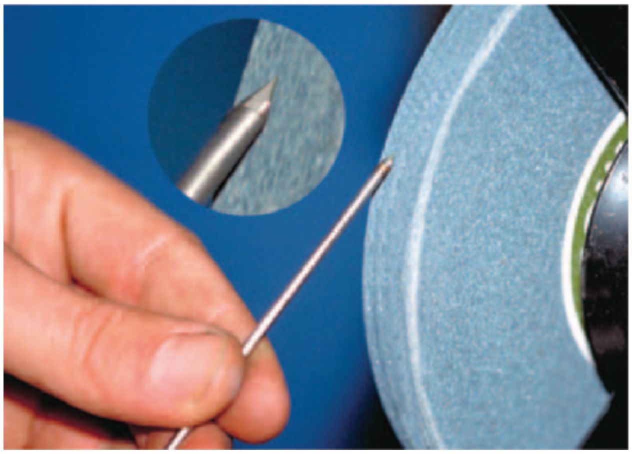

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FIGURE 16-9 Correct way of holding a tungsten when grinding.

BREAKING AND REMELTING

Most tungsten, except for lanthanated tungsten, can be broken easily because it is hard but brittle, resulting in low impact strength. If tungsten is struck sharply, it will break without bending. When it is held against a sharp corner and hit, a fairly square break will result. **Figure 16-10**, **Figure 16-11**, and **Figure 16-12** show ways to break the tungsten correctly on a sharp corner using a hammer, with two pliers, and wire cutters.

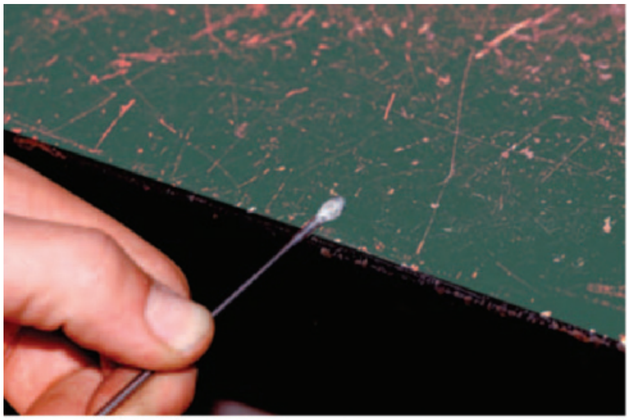

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FIGURE 16-10 Breaking the contaminated end from a tungsten by striking it with a hammer.

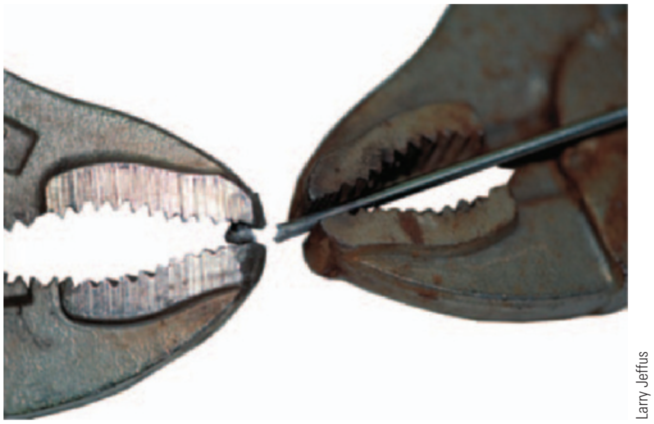


FIGURE 16-11 Correctly breaking the tungsten using two pairs of pliers.

FIGURE 16-12 Using wire cutters to correctly break the tungsten.

THINK GREEN

Recycle Tungsten

Tungsten is considered an exotic metal that can be recycled, so it is important to save the broken-off ends and short pieces. The scrap tungsten electrodes can be added to other tungsten scrap, such as worn-out tungsten carbide cutting tools, and recycled as mixed tungsten.

Once the tungsten has been broken squarely, the end must be melted back so that it becomes somewhat rounded. This is accomplished by switching the welding current to DCEP and striking an arc under argon shielding on a piece of copper. If copper is not available, then another piece of clean metal can be used. Do not use carbon because it will contaminate the tungsten.

EXPERIMENT 16-2

Removing a Contaminated Tungsten End by Breaking

Using short scrap pieces of tungsten, pliers or wire cutters, and a light machinist's hammer, you will break the end from the tungsten.

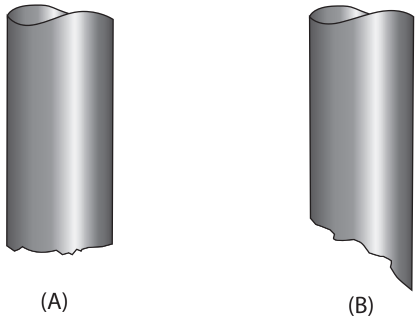


FIGURE 16-13 (A) Correctly broken tungsten electrode; (B) incorrectly broken tungsten electrode.

Break approximately 1/4 in. (6 mm) from the end of the tungsten using the appropriate method, depending on the diameter of the tungsten. Observe the break; it should be square and relatively smooth, **Figure 16-13**. The end of the tungsten should be broken only if the tungsten is badly contaminated.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

CHEMICAL CLEANING AND POINTING

The tungsten can be cleaned and pointed using one of several compounds. The tungsten is heated by shorting it against the work. The tungsten is then dipped in the compound, a strong alkaline, which rapidly dissolves the hot tungsten. The chemical reaction is so fast that enough additional heat is produced to keep the tungsten hot, **Figure 16-14**. When the tungsten is removed, cooled, and cleaned, the end will be tapered to a fine point. If the electrode is contaminated, then the chemical compound will dissolve the tungsten, allowing the contamination to fall free.

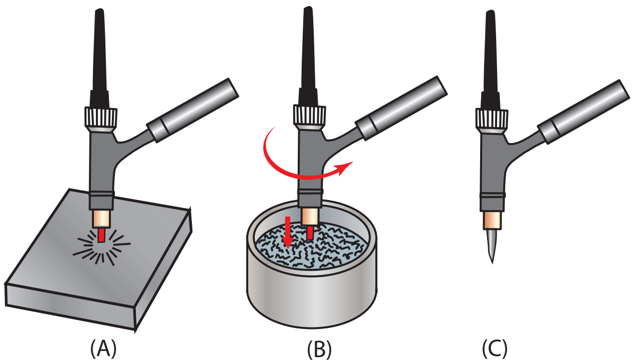


FIGURE 16-14 Chemically cleaning and pointing tungsten: (A) shorting the tungsten against the work to heat it to red hot, (B) inserting the tungsten into the compound and moving it around, and (C) cleaned and pointed tungsten ready for use.

POINTING AND REMELTING

The tapered tungsten with a balled end, a shape sometimes used for DCEP welding, is made by first grinding or chemically pointing the electrode. Using DCEP, as in the procedure for the remelted broken end, strike an arc on some copper under argon shielding and slowly increase the current until a ball starts to form on the tungsten. The ball should be made large enough so that the color of the end stays between dull red and bright red. If the color turns white, then the ball is too small and should be made larger. To increase the size of the ball, simply apply more current until the end begins to melt. Surface tension will pull the molten tungsten up onto the tapered end. Lower the current and continue welding. DCEP is seldom used for welding. If the tip is still too hot, then it may be necessary to increase the size of the tungsten.

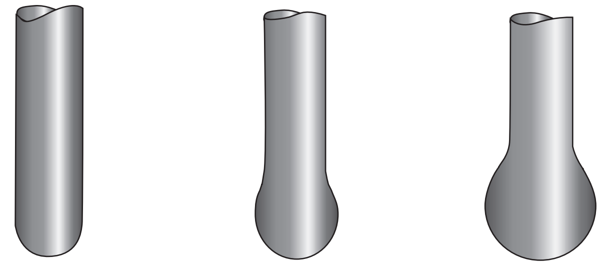


FIGURE 16-15 Melting the tungsten end shape.

EXPERIMENT 16-3

Melting the Tungsten End Shape

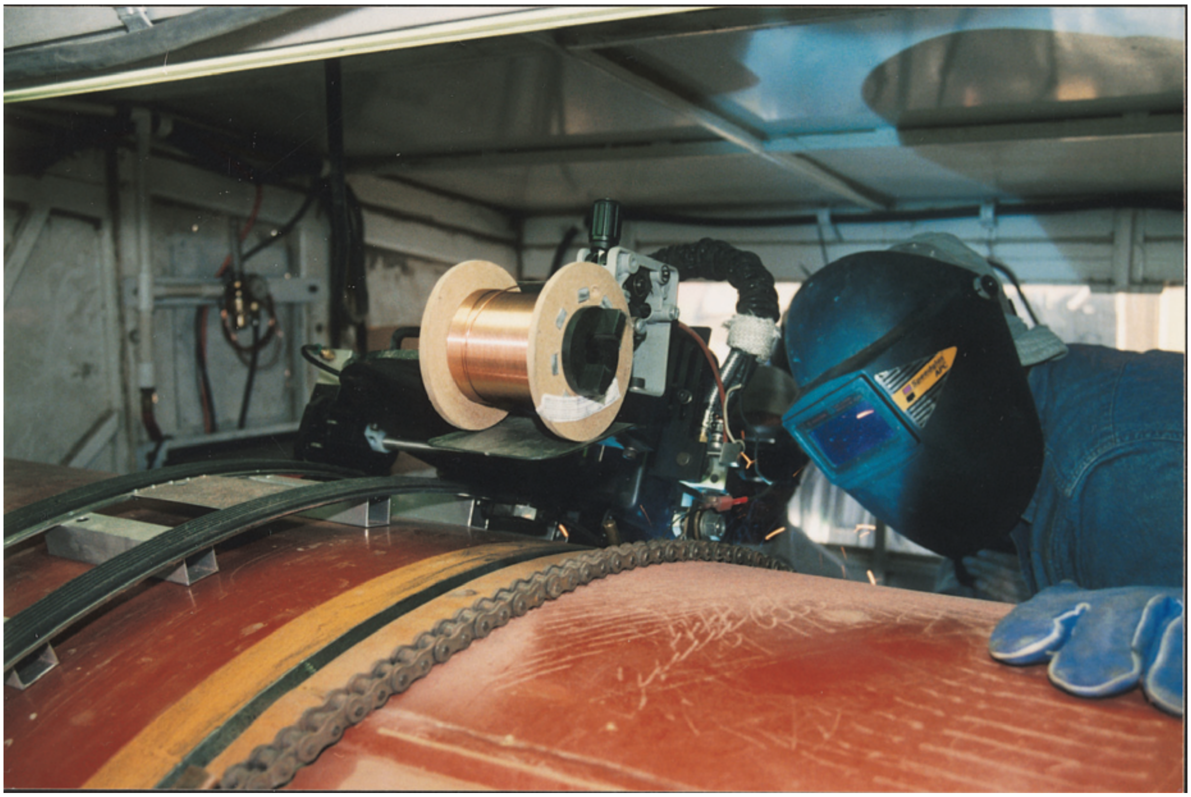
Using a properly set-up GTA welding machine, proper safety protection, one piece of copper or other clean piece of metal, and the tungsten that was sharpened and broken in Experiments 16-1 and 16-2, you will melt the end of the tungsten into the desired shape.

Properly install the tungsten, set the argon gas flow, switch the current to DCEP, and turn on the machine. Strike an arc on the copper and slowly increase the amperage. Watch the tungsten as it begins to melt and stop the current when the desired shape has been obtained, **Figure 16-15**.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

GTA WELDING EQUIPMENT

Figure 16-16 and **Figure 16-17** show two industrial applications of gas tungsten arc welding.



Courtesy of Lincoln Electric Company

FIGURE 16-16 Semiautomatic operation allows a stainless steel part to be GTA welded as it is turned past the torch.

FIGURE 16-17 An operator GTA welds a cap ring on a pneumatic tank.

Torches

GTA welding torches are available water-cooled or air-cooled. The heat transfer efficiency for GTA welding may be as low as 20%. This means that 80% of the heat generated does not enter the weld. Much of this heat stays in the torch and must be removed by some type of cooling method.

Water Cooled The water-cooled GTA welding torch is more efficient than an air-cooled torch at removing waste heat. The water-cooled torch, as compared to the air-cooled torch, operates at a lower temperature, resulting in a lower tungsten temperature and less erosion.

Air Cooled The air-cooled torch is more portable because it has fewer hoses, and it may be easier to manipulate than the water-cooled torch. Also, the water-cooled torch requires a water reservoir or other system to give the needed cooling. The cooling water system should contain some type of safety device, **Figure 16-18**, to shut off the power if the water flow is interrupted. The power cable is surrounded by the return water to keep it cool, so a smaller cable can be used. Without the cooling water, the cable quickly overheats and melts through the hose.

The water can become stopped or restricted for a number of reasons, such as a kink in the hose, a heavy object set on the hose, or failure to turn on the system. Water pressures higher than 35 psi (241 kg/mm^2) may cause the water hoses to burst. When an open system is used, a pressure regulator must be installed to prevent pressures that are too high from damaging the hoses.

FIGURE 16-18 Power cable safety fuse.

Current Range GTA welding torch heads are available in a variety of amperage ranges and designs, **Figure 16-19.** The amperage listed on a torch is the maximum rating and cannot be exceeded without possible damage to the torch.

FIGURE 16-19 GTA welding torches.

The various head angles allow better access in tight places. Some of the heads can be swiveled easily to new angles. The back cap that both protects and tightens the tungsten can be short or long, **Figure 16-20** and **Figure 16-21**.

FIGURE 16-20 Short back caps are available for torches when space is a problem.

FIGURE 16-21 Long back caps allow tungstens that are a full 7 in. (177 mm) long to be used.

Hoses

A water-cooled torch has three hoses connecting it to the welding machine. The hoses are for shielding gas to the torch, cooling water to the torch and cooling the water return, and housing the power cables to the torch, **Figure 16-22**. Air-cooled torches may have one hose for shielding gas attached to the power cable, **Figure 16-23**.

Shielding Gas Hoses The shielding gas hose must be made from a material such as plastic that will not contaminate the shielding gas. Rubber hoses contain oils that can be picked up by the gas, resulting in weld contamination.

Cooling Water Hoses The water-in hose may be made of any sturdy material. Water hose fittings have left-hand threads, and gas hose fittings have right-hand threads. This prevents the water and gas hoses from accidentally being reversed when attaching them to the welder. The return water hose also contains the welding power cable. This permits a much smaller cable to be used because the water keeps it cool.

The water must be supplied to the torch head and return around the cable. This allows the head to receive the maximum cooling from the water before the power cable warms it. Running the water through the torch first has another advantage. That is, when the water solenoid is closed, there is no water pressure in the hoses, which is particularly important. This feature also prevents condensation in the torch. If a water leak should occur during welding, the welding power is stopped, closing the water solenoid and thus stopping the leak.

Hose Protective Covers A protective covering can be used to prevent the hoses from becoming damaged by hot

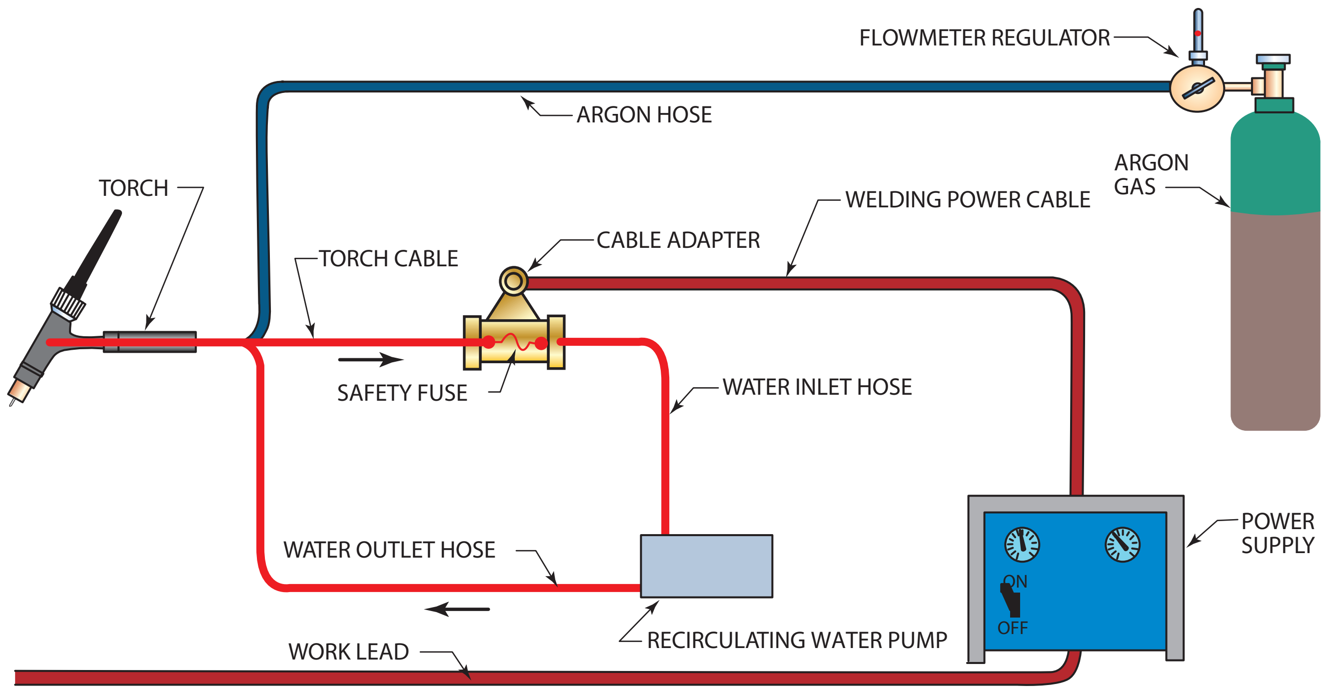


FIGURE 16-22 Schematic of a GTA welding setup with a water-cooled torch.

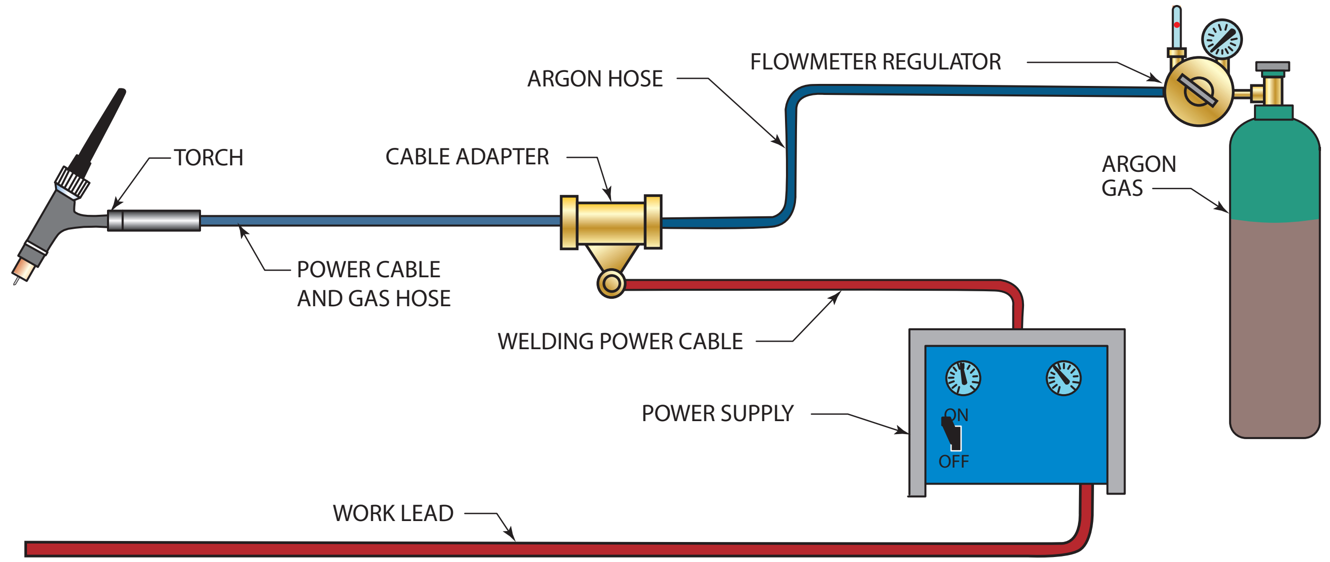


FIGURE 16-23 Schematic of a GTA welding setup with an air-cooled torch.

FIGURE 16-24 Zip-on protective covering also helps keep the hoses neat.

FIGURE 16-25 A bracket holds the leads off the floor.

metal, **Figure 16-24**. Even with this protection, the hoses should be supported, **Figure 16-25**, so that they are not underfoot on the floor. By supporting the hoses, the chance of their being damaged by hot sparks is reduced.

Tungsten Electrode Diameter		Nozzle Orifice Diameter	
in.	mm	in.	mm
1/16	2	1/4 to 3/8	6 to 10
3/32	2.4	3/8 to 7/16	10 to 11
1/8	3	7/16 to 1/2	11 to 13
3/16	4.8	1/2 to 3/4	13 to 19

TABLE 16-2 Recommended Cup Sizes

Nozzles

The nozzle or cup is used to direct the shielding gas directly on the welding zone. The nozzle size is determined by the diameter of the opening and its length, **Table 16-2**. Nozzles may be made from a ceramic such as alumina or silicon nitride (opaque) or from fused quartz (clear). The nozzle may also have a gas lens to improve the gas flow pattern.

Nozzle Size The nozzle size, both length and diameter, is often the welder's personal preference. Occasionally, a specific choice must be made based on joint design or location. Small nozzle diameters allow the welder to better see the molten weld pool and can be operated with lower gas flow rates. Larger nozzle diameters can give better gas coverage, even in drafty places.

Ceramic Nozzles The ceramic nozzles are heat-resistant and offer a relatively long life. The useful life of a ceramic nozzle is affected by the current level and proximity to the work. Silicon nitride nozzles will withstand much more heat, resulting in a longer useful life.

Fused Quartz The fused quartz (glass) used in a nozzle is a special type that can withstand the welding heat.

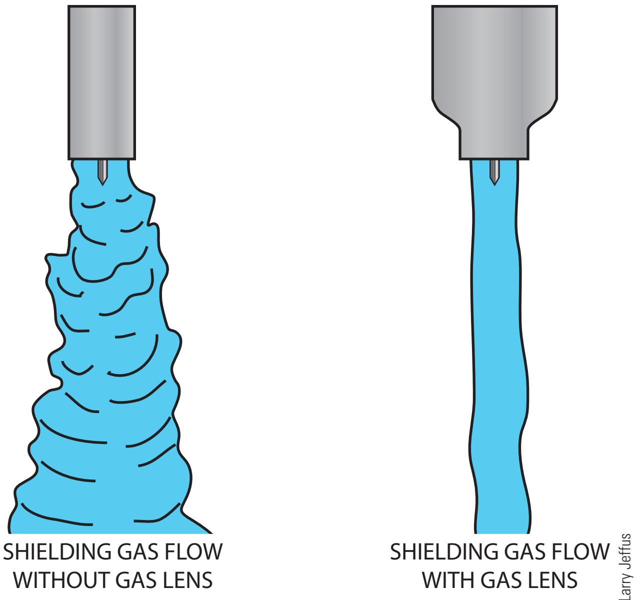


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FIGURE 16-26 Flowmeter.

These nozzles are no more easily broken than ceramic ones but are more expensive. The added visibility with glass nozzles in tight, hard-to-reach places is often worth the added expense.

The longer a nozzle, the longer the tungsten must be extended from the collet. This can cause higher tungsten temperatures, resulting in greater tungsten erosion. When using long nozzles, it is better to use low amperages or a larger size tungsten.

Gas Lens

A GTAW gas lens is a device that can be added to almost all GTA welding torches. The gas lens reduces the turbulence in the shielding gas as it leaves the nozzle, **Figure 16-26**. In doing this it provides a better shielding gas coverage of the molten weld pool, even at a significantly reduced gas flow rate.

FLOWMETER

The **flowmeter** may be merely a flow regulator used on a manifold system, or it may be a combination flow and pressure regulator used on an individual cylinder. Some flowmeters use a ball that floats on top of the flowing gas stream in a clear tube to indicate the shielding gas flow rate; other flowmeters use a gauge, **Figure 16-27** and **Figure 16-28**.

In the tube- and ball-type flowmeter, the gas flow is controlled by opening a small valve at the base of the flowmeter. The rate of flow is then read in units of CHF (cubic feet per hour), or L/min (liters per minute). The reading is taken from a fixed scale that is compared to a small ball floating on the stream of gas. Meters from various manufacturers may be read differently. For example, they may read from the top, center, or bottom of the ball, **Figure 16-29**.

FIGURE 16-27 A gas lens creates a much smoother shielding gas flow for better weld coverage.

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FIGURE 16-28 Flowmeter regulator.

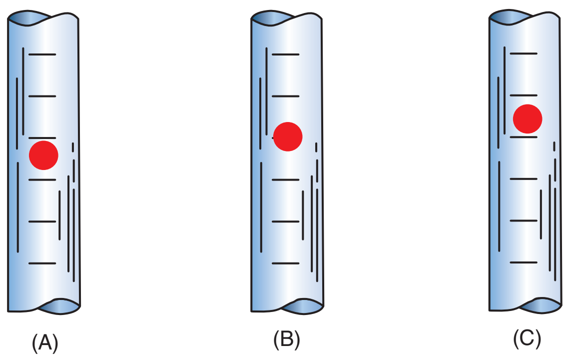

FIGURE 16-29 Three methods of reading a flowmeter: (A) top of ball, (B) center of ball, and (C) bottom of ball.

The ball floats on top of the stream of gas inside a tube that gradually increases in diameter in the upward direction. The increased size allows more room for the gas flow to pass by the ball. If the tube is not vertical, then the reading is not accurate, but the flow is unchanged. Also, when using a line flowmeter, it is important to have the correct pressure. Changes in pressure will affect the accuracy of the flowmeter reading. To get accurate readings, be sure the gas being used is read on the proper flow scale. Less dense gases, such as helium and hydrogen, will not support the ball on as high a column with the same flow rate as a denser gas, such as argon.

The tube- and ball-type flowmeters must be mounted so that the tube is perfectly vertical so that the ball will float freely inside the tube. Because the gauge-type flowmeters will read correctly at any angle, they are often preferred over the tube and ball type.

TYPES OF WELDING CURRENT

The two standard types of welding currents—alternating current (AC) and direct current (DC)—are used for GTAW. DC can be used with the electrode positive (DCEP) or with the electrode negative (DCEN). In addition to the two standard welding currents, a hybrid version of alternating current is available. Special types of welding machines produce this hybrid current electronically.

The major differences among the currents are in their heat distributions and the presence or degree of arc cleaning. **Figure 16-30** shows the heat distribution for each of the three types of currents.

DCEN

Direct-current electrode negative (DCEN), which used to be called direct-current straight polarity (DCSP), concentrates approximately two-thirds of its welding heat on the work and the remaining one-third on the tungsten. The higher heat input to the weld results in deep penetration. The low heat input into the tungsten means that a smaller-size tungsten can be used without erosion problems. The smaller-size electrode may not require pointing, resulting in savings of time, money, and tungsten.

DCEP

Direct-current electrode positive (DCEP), which used to be called direct-current reverse polarity (DCRP), concentrates only one-third of the arc heat on the plate and two-thirds of the heat on the electrode. This type of current is rarely used for welding because of its low heat input to the metal being welded. Its strong cleaning action on the base metal can be used to help prepare the surface of an aluminum or magnesium casting for welding by removing oxides from the irregular cast surface. The high heat input to the tungsten indicates that a large-size tungsten is required, and the end shape with a ball must be used.

There are many theories as to why DCEP has a **cleaning action**. The most probable explanation is that the electrons accelerated from the cathode surface lift the oxides that interfere with their movement. The positive ions accelerated to the metal's surface provide additional energy. In combination, the electrons and ions cause the surface erosion needed to produce the cleaning. Although this theory is disputed, it is important to note that cleaning does occur, that it requires argon-rich shield gases and DCEP polarity, and that it can be used to advantage, **Figure 16-31**.

AC

Alternating current (AC) concentrates approximately half of its heat on the work and the other half on the tungsten. Alternating current is DCEN half of the time and DCEP the other half of the time. The **frequency** at which the current

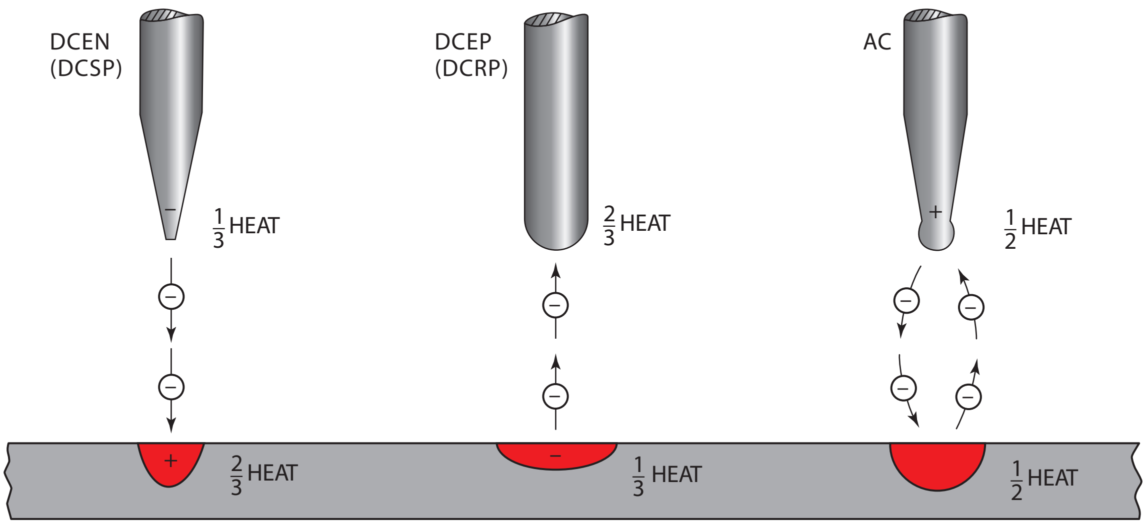

FIGURE 16-30 Heat distribution between the tungsten electrode and the work with each type of welding current.

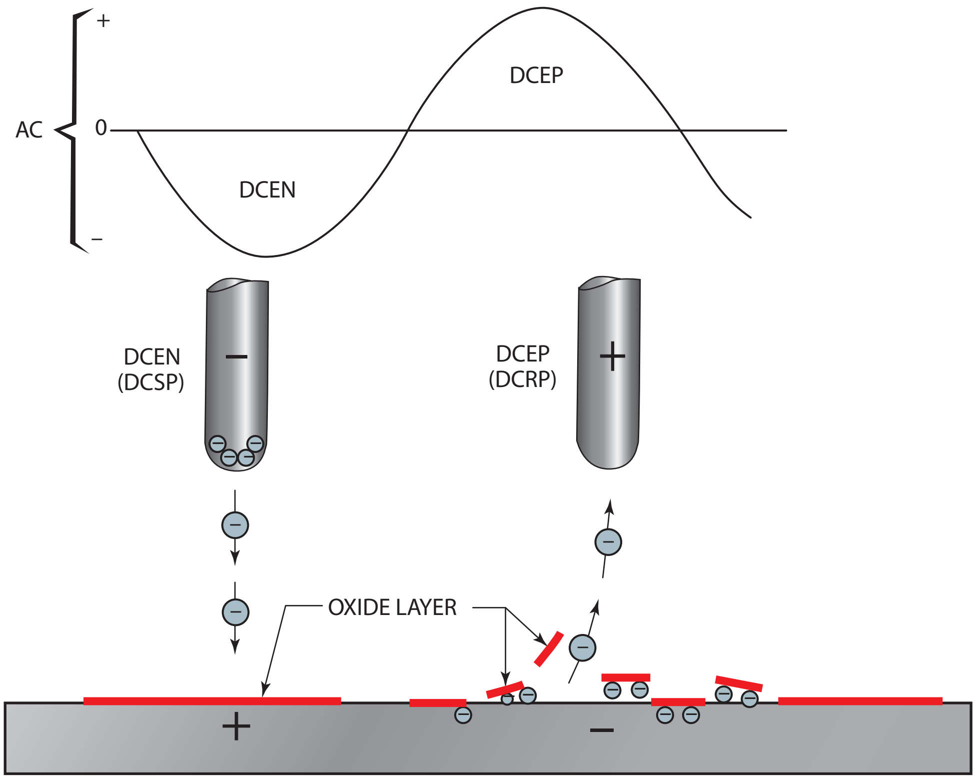

FIGURE 16-31 Electrons collect under the oxide layer during the DCEP portion of the cycle and lift the oxides from the surface.

cycles is the rate at which it makes a full change in direction, **Figure 16-32**. In the United States, the electric current cycles at the rate of 60 times per second, or 60 hertz (60 Hz). Referring again to Figure 16-32, the current is at its maximum peak at points A and B. The rate gradually decreases until it stops at points C and D. The arc at these points is extinguished and, as the current reversal begins, must be re-established. This event requires the emission of electrons from the cathode to ionize the shielding gas. When the hot, emissive electrode becomes the cathode, re-establishing the arc is easy. However, it is often quite difficult to re-establish the arc when the colder and less emissive workpiece becomes the cathode. Because voltage from the power supply is designed to support a relatively low voltage arc, it may be insufficient to initiate electron flow. Thus, a high-voltage very-low-current assist from another source is needed.

The high-frequency current can be created using a spark gap oscillator or by high-speed solid-state switches, **Figure 16-33A** and **B**. The voltage is stepped up with a transformer from the primary voltage supplied to the machine. The available amperage to the high-frequency circuit is very low. Thus, when the circuit is complete, the voltage quickly drops to a safe level. The high frequency is induced on the primary welding current in a coil.

The high frequency may be set so that it automatically cuts off after the arc is established, when welding with DC. It is kept on continuously with AC. When used in this manner, it is referred to as alternating current, high-frequency stabilized, or ACHF.

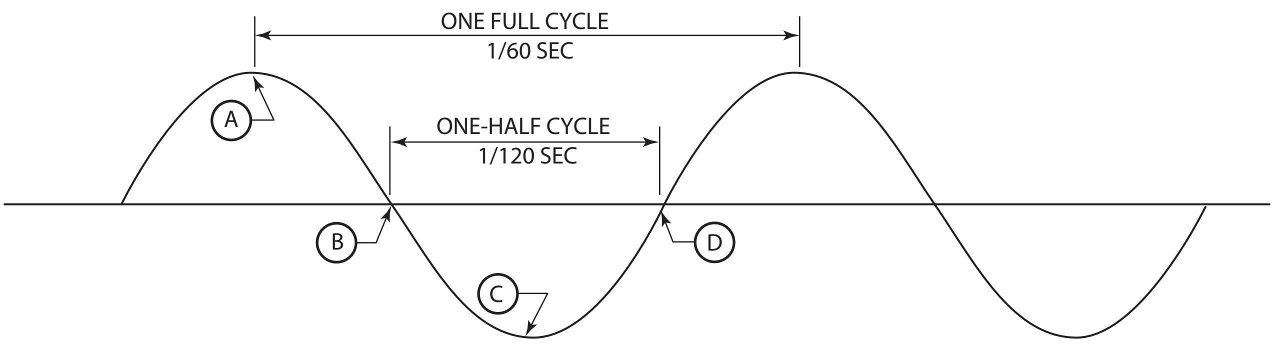

FIGURE 16-32 Sine wave of alternating current.

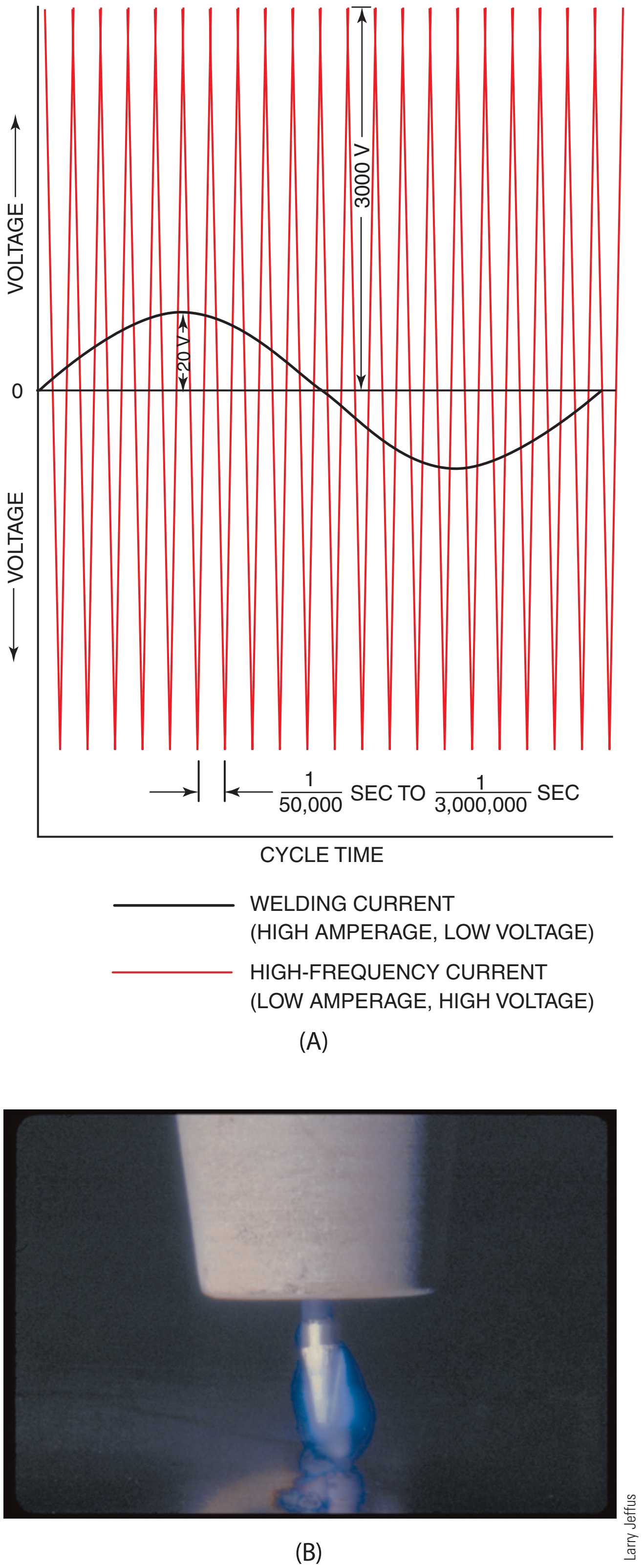

FIGURE 16-33 (A) High-frequency arc starting current shown over the low-frequency welding current. (B) The high frequency first appears as a blue glow around the tungsten before the welding current starts its arc.

ELECTRONIC CONTROLS OF AC WELDING CURRENTS

Conventional alternating current (AC) GTA welding machines operating on 60-cycle incoming line power provide 60-cycle AC welding power. Many newer GTA welding machines have electronic controls built into the welding machines that allow welders to make changes in the output power such as:

- EP and EN Time—the EP (electrode positive) portion of alternating current provides surface cleaning and the EN (electrode negative) portion of the current provides heat on the weld metal, **Figure 16-34**.
- Sine Wave Form—can be changed from the traditional sine wave of 60 cycles of power to a squarewave, soft squarewave, and/or triangular wave forms, **Figure 16-35**.

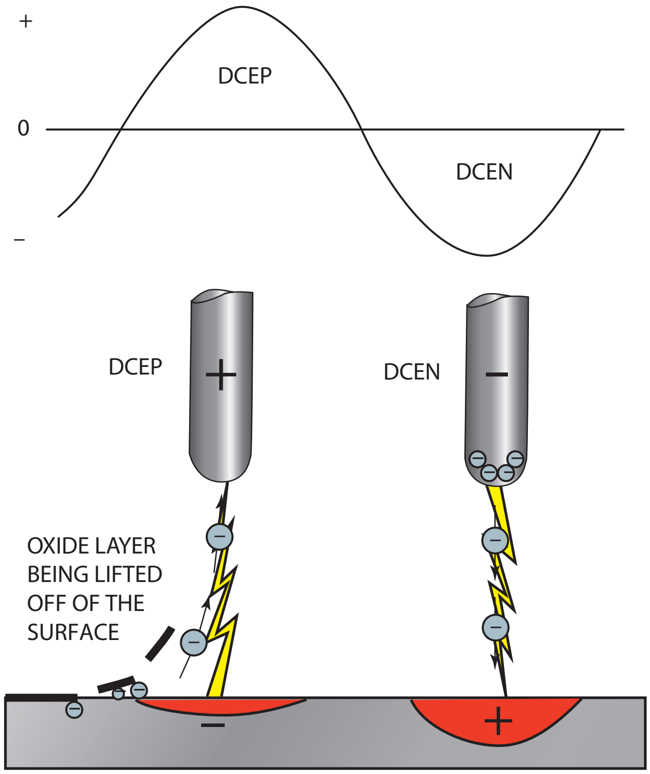

FIGURE 16-34 The electrode positive portion of the alternating current puts a little heat into the base metal while removing oxides. The electrode negative portion does not provide any cleaning as it puts most of the heat into the weld.

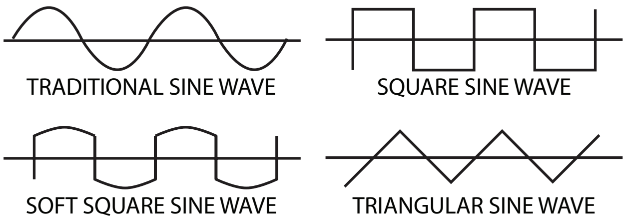

FIGURE 16-35 The four common welding current sine waves.

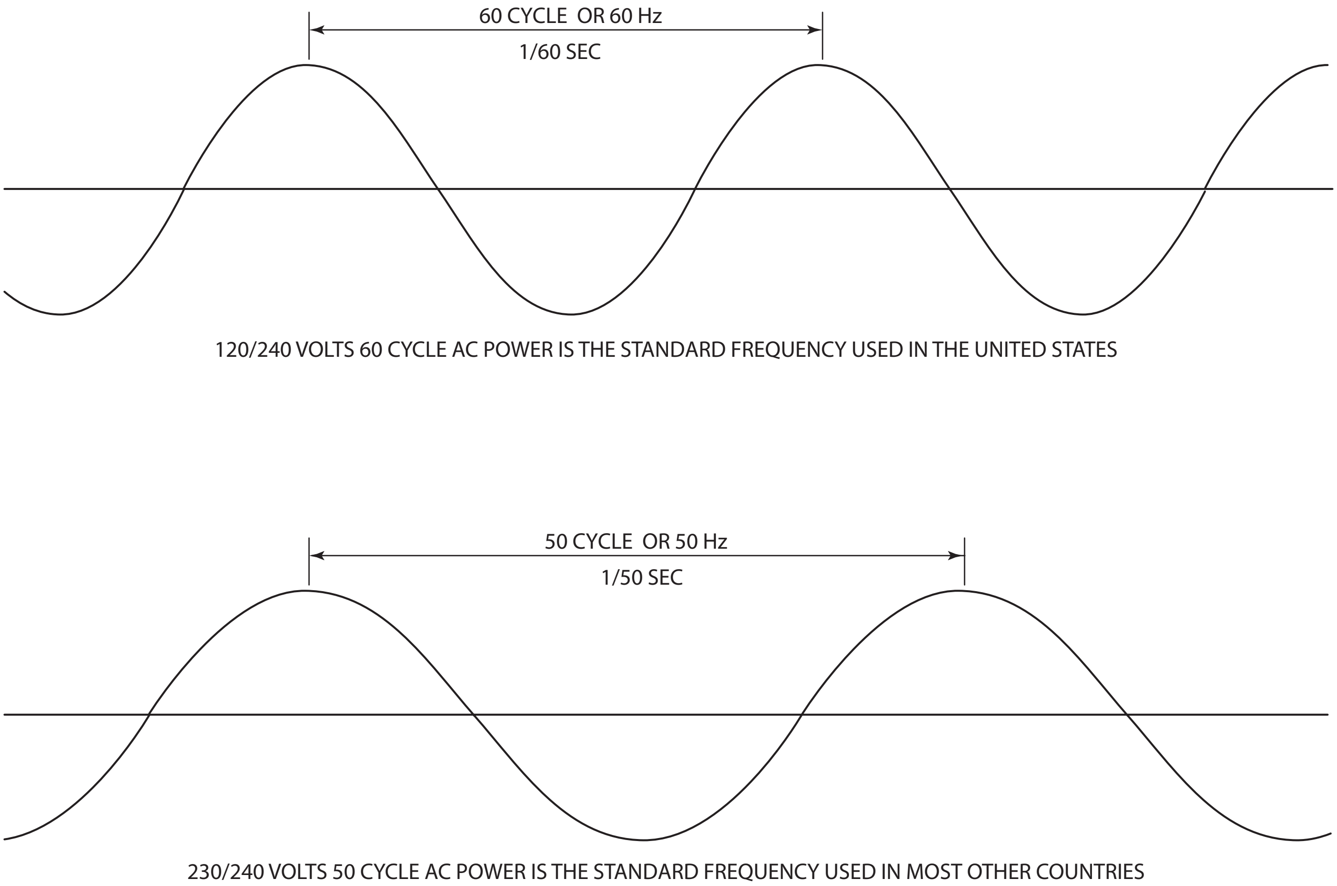

FIGURE 16-36 Comparison of 60-cycle and 50-cycle currents.

- Frequency—the rate of change from EP to EN that a sine wave has is referred to as frequency and is expressed as hertz (Hz), **Figure 16-36**.

EP and EN Time Control

The traditional alternating current provided by older welding machines had a 50/50 balance between the EP and EN portions of the welding current. The EP cleaning portion of the current on these welders was much stronger than needed for welding on new or very clean aluminum plate or pipe. With the newer electronic welding machines, the percentage of time the power is on EP or EN can be adjusted. For example, on clean, new aluminum the EP setting might be 40% and the EN side might be at 60% to give more welding heat and adequate oxide cleaning. But for welding on an aluminum casting or material that cannot be cleaned thoroughly, the EP value can be increased to keep contaminations form affecting the weld.

There are few set rules for setting the EP/EN time, so it is often left up to the welder to make the setting that works best for the current weld. One indication that the EP value might need to be increased is if you observe oxides or other surface contaminations floating on the molten weld pool.

Sine Wave Form Control

The traditional AC sine wave provides good surface wetting, which allows the molten weld pool to flow easily into the joint or onto the metal surface.

The squarewave was the first vernation of the AC welding current's sine wave. It provided the welder with a current that allowed the molten weld pool to have both deeper penetration and faster solidification. Both of these characteristics made controlling the weld much easier, especially for out of position welds. In addition, faster travel rates could be obtained while still maintaining weld penetration and quality.

The soft squarewave combined the good surface wetting characteristics of the traditional AC sine wave with the improved molten weld pool control of the squarewave. It is a good balance between the two waveforms.

The triangular waveform reduces the heat input without sacrificing the arc control. It is useful for welding on thin sections and for higher travel speeds.

Frequency Control

Depending on the welding machine, the frequency may be set as low as 20 Hz and as high as 250 Hz. The lower setting produces a much less focused arc and the higher

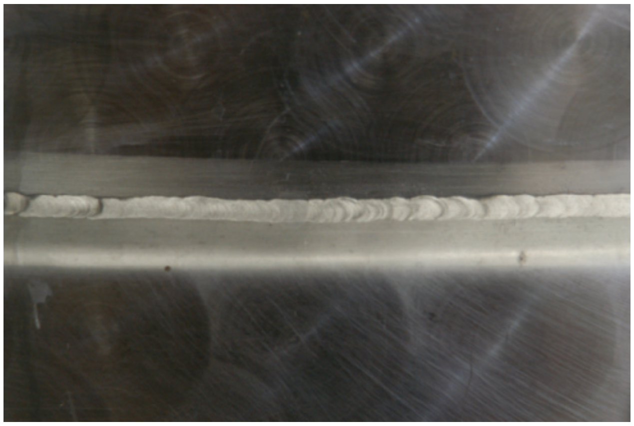

FIGURE 16-37 Uneven heating resulted in underfill along the top edge of this lap joint.

setting provides a much more concentrated, stiffer, and more focused arc. Most welding is preformed with a setting between 100 Hz and 120 Hz. Higher frequencies are often used for machine or automated GTA welding, for which higher travel speeds are possible.

The higher the frequency, the stiffer and more focused the arc is, which is particularly helpful in fillet welds, where the edge of one plate is being heated and the middle of the base plate is not, **Figure 16-37**. The stiffer and more focused arc will allow the welder to direct the heat on the base plate because it will take more heat to melt due to its thermal mass.

SHIELDING GASES

The shielding gases used for the GTA welding process are argon (Ar), helium (He), hydrogen (H), nitrogen (N), or a mixture of two or more of these gases. The purpose of the shielding gas is to protect the molten weld pool and the tungsten electrode from the harmful effects of air. The shielding gas also affects the amount of heat produced by the arc and the resulting weld bead appearance.

Argon and helium are **noble inert gases**. This means that they will not combine chemically with any other material. Argon and helium may be found in mixtures, but never as compounds. Because they are inert, they will not affect the molten weld pool in any way.

CAUTION

Never allow noninert gases such as O_2, CO_2, or N to come in contact with your inert gas system. Very small amounts can contaminate the inert gas, which may result in the weld failing.

Argon

Argon makes up approximately 1% of air and is a by-product of the air reduction process that is used in the production of oxygen. Air can be separated cryogenically or noncryogenically. Cryogenic air separation plants cool air down to approximately −300°F (−185°C), a low enough temperature to cause it to liquefy. The various gases that make up air are separated using a distillation process. In the distillation process, the liquid is gradually allowed to warm so that each gas will boil off at its specific temperature.

There are several other types of noncryogenic processes used to separate oxygen and nitrogen from air. However, only the molecular sieve process can produce the level of purity needed for some GTA welding. In the molecular sieve process, a material that has tiny pores small enough to separate the different gasses based on their molecular size is used. This process works much like sifting sand through a screen to separate rocks from the sand.

Because argon is denser than air, it effectively shields welds in deep grooves in the flat position. However, this higher density can be a hindrance when welding overhead because higher flow rates are necessary. The argon is relatively easy to ionize and thus suitable for alternating-current applications and easier starts. This property also permits fairly long arcs at lower voltages, making it virtually insensitive to changes in arc length. Argon is also the only commercial gas that produces the cleaning discussed previously. These characteristics are most useful for manual welding, especially with filler metals added, as shown in **Figure 16-38**.

Helium

Helium is a by-product of the natural gas industry. It is removed from natural gas as the gas undergoes separation (fractionation) for purification or refinement.

Helium offers the advantage of deeper penetration. The arc force with helium is sufficient to displace the molten weld pool with very short arcs. In some mechanized applications, the tip of the tungsten electrode is positioned below the workpiece surface to obtain very deep and narrow penetration. This technique is especially effective for welding aged aluminum alloys prone to overaging. It also is very effective at high welding speeds, as for tube mills. However, helium is less forgiving for manual welding. With helium, penetration and bead profile are sensitive to

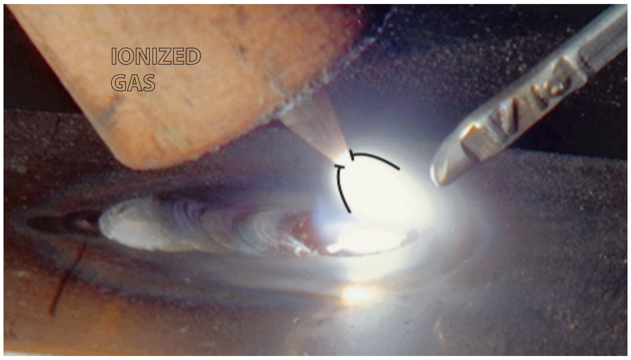

FIGURE 16-38 Highly concentrated ionized argon gas column.

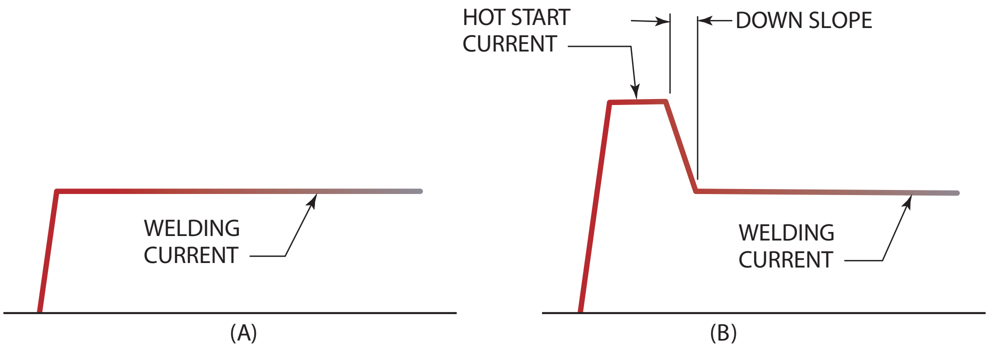

FIGURE 16-39 Standard method of starting welding current (A); hot start method of starting welding current (B).

the arc length, and the long arcs needed for feeding filler wires are more difficult to control.

Helium has been mixed with argon to gain the combined benefits of cathode cleaning and deeper penetration, particularly for manual welding. The most common of these mixtures is 75% helium and 25% argon.

Although the GTA process was developed with helium as the shielding gas, argon is now used whenever possible because it is much cheaper. Helium also has some disadvantages because it is lighter than air, thus preventing good shielding. Its flow rates must be approximately twice as high as argon's for acceptable stiffness in the gas stream, and proper protection is difficult in drafts unless high flow rates are used. It is difficult to ionize, necessitating higher voltages to support the arc and making the arc more difficult to ignite. Alternating-current arcs are very unstable. However, helium is not used with alternating current because the cleaning action does not occur.

Hydrogen

Hydrogen is not an inert gas and is not used as a primary shielding gas. However, it can be added to argon when deep penetration and high welding speeds are needed. It also improves the weld surface cleanliness and bead profile on some grades of stainless steel that are very sensitive to oxygen. Hydrogen additions are restricted to stainless steel because hydrogen is the primary cause of porosity in aluminum welds. It can cause porosity in carbon steels and, in highly restrained welds, underbead cracking in carbon and low alloy steels.

Nitrogen

Nitrogen is not an inert gas. Like hydrogen, nitrogen has been used as an additive to argon. However, it cannot be used with some materials, such as ferritic steels, because it produces porosity. In other cases, such as with austenitic stainless steels, nitrogen is useful as an austenite stabilizer in the alloy. It is used to increase penetration when welding copper. Unfortunately, because of the general success with inert gas mixtures and because of potential metallurgical problems, nitrogen has not received much attention as an additive for GTA welding.

HOT START

The hot start allows a controlled surge of welding current as the arc is started to establish a molten weld pool quickly. Establishing a molten weld pool rapidly on metals with a high thermal conductivity is often difficult without this higher-than-normal current. Adjustments can be made in the length of time and the percentage above the normal current, **Figure 16-39**.

PREFLOW

The **preflow** is the time during which gas flows to clear out any air in the nozzle or surrounding the weld zone. The welding torch must be held directly over the joint that is going to be welded so that the preflow shielding will force the air away from the welding zone before the arc starts.

The operator sets the length of time that the gas flows before the welding current is started, **Figure 16-40**. Because some machines do not have preflow, many welders find it difficult to hold a position while waiting for the

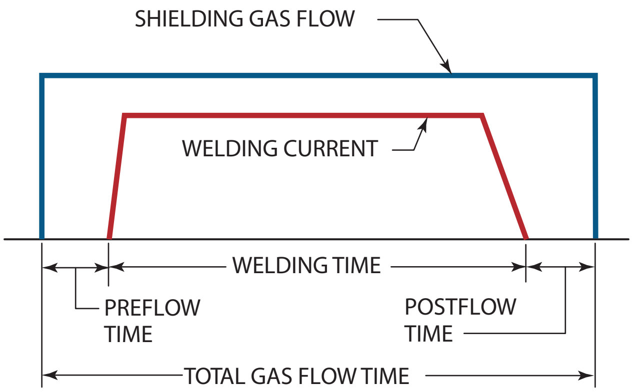

FIGURE 16-40 Welding time compared to shielding gas flow time.

current to start. One solution to this problem is to use the postflow for preflow. Switch on the current to engage the postflow. Now, with the current off, the gas is flowing, and the GTA torch can be lowered to the welding position. The welder's helmet should be lowered and the current restarted before the postflow stops. This allows welders to have postflow and to start the arc when they are ready.

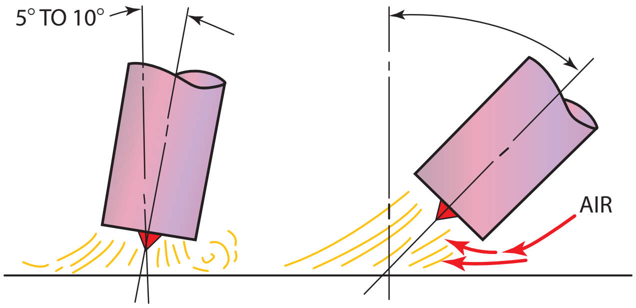

FIGURE 16-41 Too steep of an angle between the torch and work may draw in air.

POSTFLOW

The **postflow** is the time during which the gas continues flowing after the welding current has stopped. This period serves to protect the molten weld pool, the filler rod, and the tungsten electrode as they cool to a temperature at which they will not oxidize rapidly. The time of the flow is determined by the welding current and the tungsten size, **Table 16-3**. During the postflow time, the torch must be held directly over the cooling weld pool so that it is protected from atmospheric contamination.

Nozzle Inside Diameter		Gas Flow*	
in.	mm	cfh	L/min
1/4	6	10-14	4.7-6.6
5/16	8	11-15	5.2-7.0
3/8	10	12-16	5.6-7.5
7/16	11	13-17	6.1-8.0
1/2	13	17-20	8.0-9.4
5/8	16	17-20	8.0-9.4

*The flow rates may need to be increased or decreased depending upon the conditions under which the weld is to be performed.

TABLE 16-4 Suggested Argon Gas Flow Rate for Given Cup Sizes

SHIELDING GAS FLOW RATE

The shielding gas flow rate is measured in cubic feet per hour (CFH) or in metric measure as liters per minute (L/min). The rate of flow should be as low as possible and still give adequate coverage. High gas flow rates waste shielding gases and may lead to contamination. The contamination comes from turbulence in the gas at high flow rates. Air is drawn into the gas envelope by a venturi effect around the edge of the nozzle. Also, the air can be drawn in under the nozzle if the torch is held at too sharp of an angle to the metal, **Figure 16-41**.

The larger the nozzle size, the higher is the flow rate permissible without causing turbulence. **Table 16-4** shows the average and maximum flow rates for most nozzle sizes. A gas lens can be used in combination with the nozzle to stabilize the gas flow, thus eliminating some turbulence. A gas lens will add to the turbulence problem if there is any spatter or contamination on its surface, **Figure 16-42.**

FIGURE 16-42 Gas lens.

Electrode Diameter		Postwelding Gas Flow Time*
in.	mm	
0.01	0.25	5 sec
0.02	0.5	5 sec
0.04	1.0	5 sec
1/16	2	8 sec
3/32	2.4	10 sec
1/8	3	15 sec
5/32	4	20 sec
3/16	4.8	25 sec
1/4	6	30 sec

*The time may be longer if either the base metal or the tungsten electrode does not cool below the rapid oxidation temperatures within the postpurge times shown.

TABLE 16-3 Postwelding Gas Flow Times

Shielding gas dams may be placed on the sides of the joint to be welded so that the shielding gas will flood the weld zone better. The gas dams can be made by clamping metal pieces alongside the joint or by using a high-temperature tape to hold thin foil or sheet metal in place. Shielding gas dams should be used anytime there is more than just a light draft or breeze and when reactive metals such as titanium are being welded.

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FIGURE 16-43 A foot-operated device can be used to increase the current.

REMOTE CONTROLS

A remote control can be used to start the weld, increase or decrease the current, and stop the weld. The remote control can be either a foot-operated or hand-operated device. The foot control works adequately if the welder can be seated. Welds that must be performed away from a welding station may use a hand or thumb control or may not have any remote welding controls.

THINK GREEN

Conserve Argon Shielding Gas

It takes a lot of electrical power to separate argon from air. Hundreds of kilowatts of electrical power are needed to operate a small air reduction plant, and a large air reduction plant can use tens of thousands of kilowatts. So, using as low of a shielding gas flow rate as possible will both save argon and reduce pollution caused by power plants needed to produce it.

Most remote controls have an on-off switch that is activated at the first or last part of the control movement. A variable resistor increases the current as the control is pressed more. A variable resistor works in a manner similar to the accelerator pedal on a car to increase the power (current), **Figure 16-43.** The operating amperage range is determined by the value that has been set on the main controls of the machine.

Courtesy of Lincoln Electric Company

FIGURE 16-44 GTA welding unit that can be added to a standard power supply so that it can be used for GTA welding.

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FIGURE 16-45 Always be sure the power is off when making machine connections.

EXPERIMENT 16-4

Setting Up a GTA Welder

Using a GTA welding machine, remote control welding torch, gas flowmeter, gas source (cylinder or manifold), tungsten, nozzle, collet, collet body, cap, and any other hoses, special tools, and equipment required, you will set up the machine for GTA welding, **Figure 16-44.**

1. Start with the power switch off, **Figure 16-45**. Use a wrench to attach the torch hose to the machine. The water hoses should have left-hand threads to prevent incorrectly connecting them. Tighten the fittings only as tightly as needed to prevent leaks, **Figure 16-46**. Attach the cooling water "in" to the machine solenoid and the water "out" to the power block.
2. The flowmeter or flowmeter regulator should be attached next. If a gas cylinder is used, secure it in place with a safety chain. Then, remove the valve protection cap and crack the valve to blow out any dirt, **Figure 16-47**. Attach the flowmeter so that the tube is vertical.
3. Connect the gas hose from the meter to the gas "in" connection on the machine.

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FIGURE 16-46 Tighten each fitting as it is connected to avoid missing a connection.

FIGURE 16-47 During transportation or storage, dirt may collect in the valve. Cracking the valve is the best way to remove any dirt.

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FIGURE 16-48 Setting the current.

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FIGURE 16-49 Setting the amperage range.

4. With both the machine and main power switched off, turn on the water and gas so that the connection to the machine can be checked for leaks. Tighten any leaking fittings to stop the leak.
5. Turn on both the machine and main power switches and watch for leaks in the torch hoses and fittings.
6. With the power off, switch the machine to the GTA welding mode.
7. Select the desired type of current and amperage range, **Figure 16-48** and **Figure 16-49**.
8. Set the fine current adjustment to the proper range, depending on the size of tungsten used, **Table 16-5**. Refer to Chapter 3 for more information on setting the fine current adjustment.
9. Place the high-frequency switch in the appropriate position, auto (HF start) for DC or continuous for AC, **Figure 16-50**.
10. The remote control can be plugged in and the selector switch set, **Figure 16-51**.
11. The collet and collet body should be installed on the torch first, **Figure 16-52**.
12. On the Linde or copies of Linde torches, installing the back cap first will stop the collet body from being screwed into the torch fully. A poor connection will result in excessive electrical and thermal resistance, causing a heat buildup in the head.

Electrode Diameter		DCEN	DCEP	AC
in.	mm			
0.04	1	15–60	Not recommended	10–50
1/16	2	70–100	10–20	50–90
3/32	2.4	90–200	15–30	80–130
1/8	3	150–350	25–40	100–200
5/32	4	300–450	40–55	160–300

TABLE 16-5 Amperage Range of Tungsten Electrodes

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FIGURE 16-50 The high-frequency switch should be placed in the appropriate position.

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FIGURE 16-51 Setting the remote control switch.

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FIGURE 16-52 Inserting collet and collet body.

13. The tungsten can be installed and the end cap tightened to hold the tungsten in place.
14. Select and install the desired nozzle size. Adjust the tungsten length so that it does not stick out more than the diameter of the nozzle, **Figure 16-53**.
15. Check the manufacturer's operating manual for the machine to ensure that all connections and settings are correct.

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FIGURE 16-53 Install the nozzle (cup) to the torch body.

16. Turn on the power, depress the remote control, and again check for leaks.
17. While the postflow is still engaged, set the gas flow by adjusting the valve on the flowmeter.

CAUTION

Turn off all power before attempting to stop any leaks in the water system.

The GTA welding system is now ready to be used.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

EXPERIMENT 16-5

Striking an Arc

Using a properly set-up GTA welding machine, proper safety gear, and clean scrap metal, you will strike a GTA welding arc.

1. Position yourself so that you are comfortable and can see the torch, tungsten, and plate while the tungsten tip is held approximately 1/4 in. (6 mm) above the metal. Try to hold the torch at a vertical angle ranging from 0° to 15°. Too steep of an angle will not give adequate gas coverage, **Figure 16-54**.
2. Lower your arc welding helmet and depress the remote control. A high-pitched, erratic arc should be immediately jumping across the gap between the tungsten and the plate. If the high-frequency arc is not established, lower the torch until it appears, **Figure 16-55.**
3. Slowly increase the current until the main welding arc appears, **Figure 16-56**.
4. Observe the color change of the tungsten as the arc appears.
5. Move the tungsten around in a small circle until a molten weld pool appears on the metal.

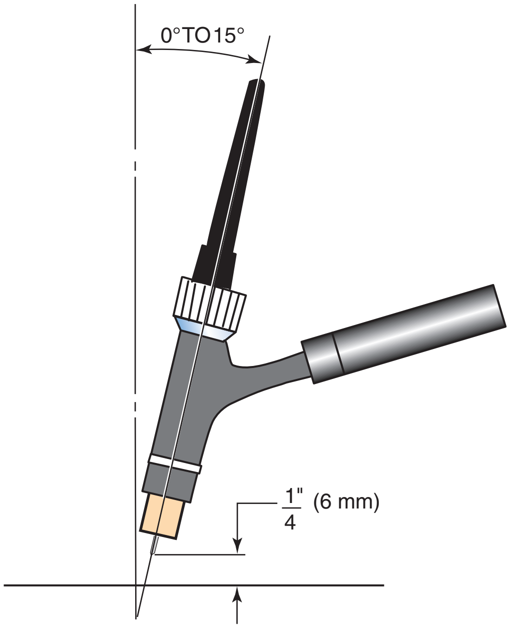

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FIGURE 16-54 GTA torch position.

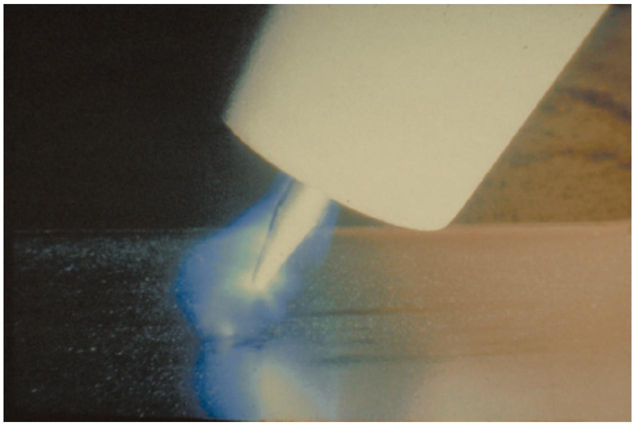

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FIGURE 16-55 High-frequency starting before arc starts.

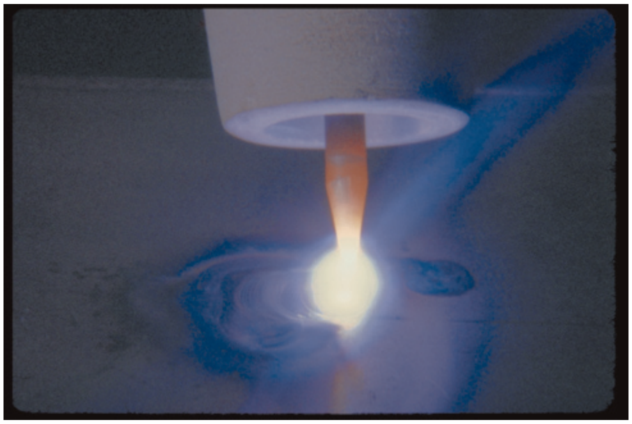

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FIGURE 16-56 Stable gas tungsten arc.

6. Slowly decrease the current and observe the change in the molten weld pool.
7. Reduce the current until the arc is extinguished.
8. Hold the torch in place over the weld until the postflow stops.
9. Raise your hood and inspect the weld.

CAUTION

Avoid touching the metal table with any unprotected skin or jewelry. The high frequency can cause an uncomfortable shock.

Repeat this procedure until you can easily start the arc and establish a molten weld pool using both AC and DCEN currents. Turn off the welding machine, water, and shielding gas when you are finished. Finally, clean your work area.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

Summary

One of the prime considerations for gas tungsten arc welding equipment setup is the cleanliness of the equipment, supplies, base material or materials, and the welders themselves. When everything is clean, you will find that the welding process will proceed more easily and more successfully.

Another major factor affecting your ability to produce quality welds is the tungsten end or tip shape. As you practice making the various welds, you will find that keeping the tungsten electrode tip shaped appropriately will assist you in producing uniform welds.

Often, new welders feel that there is some sort of attraction between the tungsten electrode, filler metal, and base metal during the welding process because it seems to continually become contaminated. This almost continuous contamination can be very frustrating. At times it may seem overwhelming; however, with continued practice and diligence you will be able to control this problem. Even experienced welders in the field can be plagued from time to time with tungsten contamination. At other times, they can weld an entire day without contaminating the tungsten. It is often beneficial for students to realize that tungsten contamination is just part of the process, and they must therefore try to ignore the possibility of it happening and concentrate on producing the welds.

Review

1. What early advancements made the GTA welding process more effective and reduced its cost?
2. What metals were weldable only by the GTAW process before GMAW was developed?
3. Which two of tungsten's properties make it the best choice for GTA welding?
4. Why must the tip of the tungsten be hot?
5. Why does some tungsten erosion occur?
6. What functions regarding tungsten heat do the collet and torch play?
7. What problem can an excessively large tungsten cause?
8. What holds the molten ball of tungsten in place at the tip of the electrode during DCEP welding?
9. Using Table 15-1, answer the following:
   a. What color identifies EWTh-1?
   b. What is the composition of EWCe-2?
10. What does adding thorium oxide do for the tungsten electrode?
11. How can the end of a tungsten electrode be shaped?
12. Why should a grinding stone that is used for sharpening tungsten not be used for other metals?
13. Why should the grinding marks run lengthwise on the tungsten electrode end?
14. What are three ways of breaking off the contaminated end of a tungsten electrode?
15. What is the correct color to use on the balled end of a pointed and remelted tungsten tip on DCEP?
16. Why should the torch be as cool as possible?
17. What will happen to a water-cooled torch cable if the flow of cooling water stops?
18. Why must shielding gas hoses not be made from rubber?
19. What materials can be used to make nozzles?
20. What problem can a long nozzle cause to the tungsten?
21. Why must the tube of a flowmeter be vertical?
22. What is the heat distribution with DCEN welding current?
23. What is the heat distribution with DCEP welding current?
24. What is the heat distribution with AC welding current?
25. Why must AC welding power use high frequencies to work?
26. Why are argon and helium known as inert gases?
27. Why is argon's ease of ionization a benefit?
28. What makes helium difficult to use for manual welding?
29. What are the benefits of adding hydrogen to argon for welding?
30. What is the purpose of a hot start?
31. Using Table 16-3, determine the gas postflow time for a 3/32-in. (2.4-mm) tungsten.
32. What functions can a remote control provide the welder?
33. Using Table 16-4, determine the minimum gas flow rate for a 1/2-in. (13-mm) nozzle.

Chapter 17

Gas Tungsten Arc Welding of Plate

OBJECTIVES

After completing this chapter, the student should be able to

- name the applications for which the gas tungsten arc welding (GTAW) process is more commonly used.
- discuss the effects on the weld of varying torch angles.
- explain why the filler rod end must be kept inside the protective zone of the shielding gas and how to accomplish this.
- tell how tungsten contamination occurs and what should be done when it happens.
- explain what can cause the actual welding amperage to change.
- determine the correct machine settings for the minimum and maximum welding current for the machine used, the types and sizes of tungsten, and the metal types and thicknesses.
- list factors that affect the gas preflow and postflow times required to protect the tungsten and the weld.
- determine the minimum and maximum gas flow settings for each nozzle size, tungsten size, and amperage setting.
- compare the characteristics of low carbon and mild steels, stainless steel, and aluminum with respect to GTA welding.
- describe the metal preparation needed before GTA welding.
- demonstrate how to properly make GTA welds in butt joints, lap joints, and tee joints in all positions that can pass the specified standard.

KEY TERMS

chill plate

contamination

gas coverage

oxide layer

protective zone

surface tension

INTRODUCTION

The gas tungsten arc welding process can be used to join nearly all types and thicknesses of metal. Welders can have a clear unobstructed view of the molten weld pool because GTA welding is fluxless, slagless, and smokeless. The clear view of the weld allows welders to make changes in their welding technique, current, travel speed, or rate of filler metal being added to the weld as the weld progresses to ensure that a quality weld is being made. This gives the welder a very fine control of the welding process.

The fine control of the weld that is possible with GTA welding makes it an ideal process for very close-tolerance, high-quality welds. GTA welding is used to make critical welds such as those on aircraft structures, which, if they fail, can cause serious injury, death, and/or significant loss of property. Sometimes GTA welding is used to make the critical root pass of a weld that will be completed using another faster process. It is also used when weld appearance is important to the look of the finished part, such as for some furniture, decorations, and/or sculptures.

The proper setup of GTA equipment can often affect the quality of the weld performed. Charts and graphs are available that give the correct amperage, gas flow rate, and time for various types of welds and metals. These charts are designed for optimum laboratory or classroom conditions. Actual conditions in the field will have an effect on these values. The experiments in this chapter are designed to help the welder understand the harmful effects on welding of less-than-ideal conditions. This will allow the welder to evaluate the appearance of a weld and make the necessary changes in technique or setup to improve the weld.

After a person has learned to weld in the lab, troubleshooting field welding problems will become much easier. The weld should be watched carefully to pick up changes that indicate a needed adjustment. When welders can do this, they have mastered the GTA process and have made themselves better potential employees. To make a weld is good; to solve a welding problem is better.

TORCH ANGLE

The torch should be held as close to perpendicular as possible in relation to the plate surface. The torch may be angled from 0° to 15° from perpendicular for better visibility and still have the proper shielding **gas coverage**. As the gas flows out it must form a **protective zone** around the weld. Tilting the torch changes the shape of this protective zone, **Figure 17-1**. Too much tilting of the torch will cause the protective shielding gas zone to become so distorted that the weld may not be protected from contamination from the air. The closer the torch is held to perpendicular, the better the weld is shielded.

The velocity of the shielding gas also affects the protective zone as the torch angle changes. As the velocity increases, a low-pressure area develops behind the cup. When the low-pressure area becomes strong enough, air is pulled into the shielding gas. The sharper the angle and the higher the flow rate, the possibility of contamination

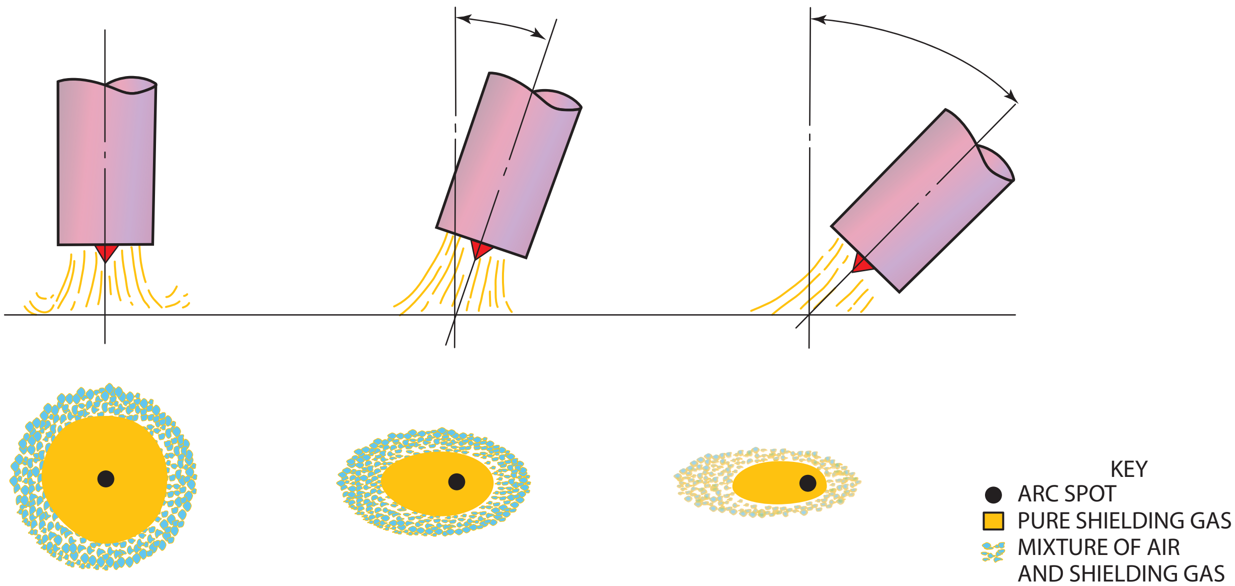

FIGURE 17-1 Gas coverage patterns for different GTA torch angles. Note how the area covered by the shielding gas becomes narrower and elongates as the angle of the torch increases from the perpendicular.

is increased by the onset of turbulence in the gas stream. This causes air to become mixed with the shielding gas. Turbulence caused by the shielding gas striking the work will also cause air to mix with the shielding gas at high velocities.

FILLER ROD MANIPULATION

The filler rod end must be kept inside the protective zone of the shielding gas, **Figure 17-2**. The end of the filler rod is hot, and if it is removed from the gas protection, it will oxidize rapidly. The oxide will then be added to the molten weld pool, **Figure 17-3**. When a weld is stopped so that the welder can change position, the shielding gas must be kept flowing around the rod end to protect it until it is cool. If the end of the rod becomes oxidized, then it should be cut off before restarting. The following method can be used both to protect the rod end and reduce the possibility of crater cracking—that is, breaking the arc but keeping the torch over the crater while, at the same time, sticking the rod in the molten weld pool before it cools, **Figure 17-4**. When the weld is restarted, the rod is simply melted loose again, **Figure 17-5**.

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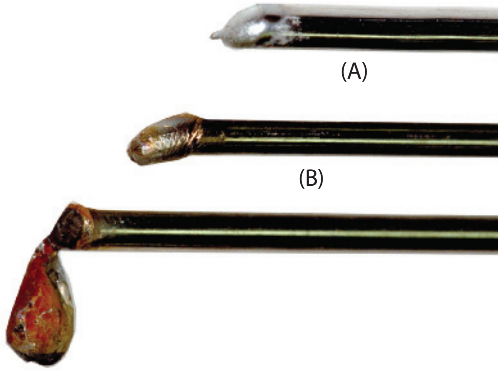
FIGURE 17-2 The hot filler rod end is well within the protective gas envelope.



(A)

(B)

(C)

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FIGURE 17-3 (A) Filler properly protected, (B) some oxides on filler, (C) and excessive oxides caused by improper filler rod manipulation.

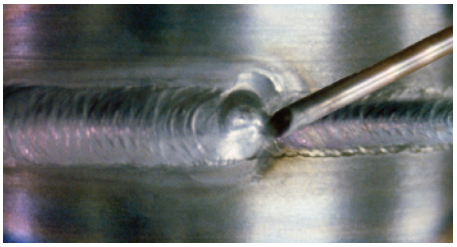

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FIGURE 17-4 Filler being left in the molten weld pool as the arc is extinguished.

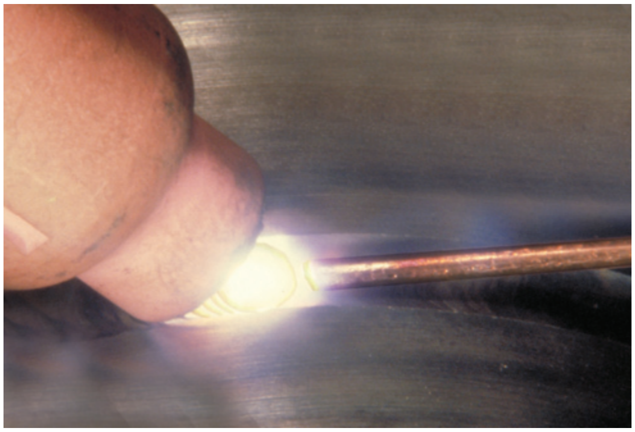

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FIGURE 17-5 Filler being remelted as the weld is continued.

The rod should enter the shielding gas as close to the base metal as possible, **Figure 17-6**. A 15° angle or less to the plate surface prevents air from being pulled into the welding zone behind the rod, **Figure 17-7**. As an example, if a rod is held in a stream of running water, air can be pulled in. The faster the water flows or the steeper the angle at which the rod is held, the more air is pulled in. The same action occurs with the shielding gas as its flow increases or as the rod angle increases.

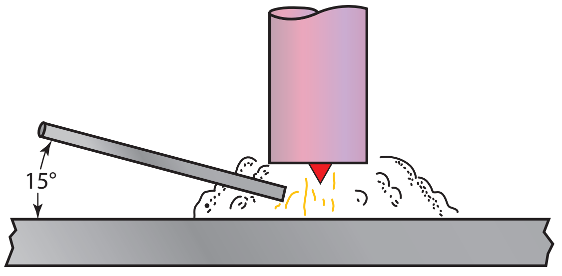

FIGURE 17-6 Keep the filled metal at an angle of approximately 15°.

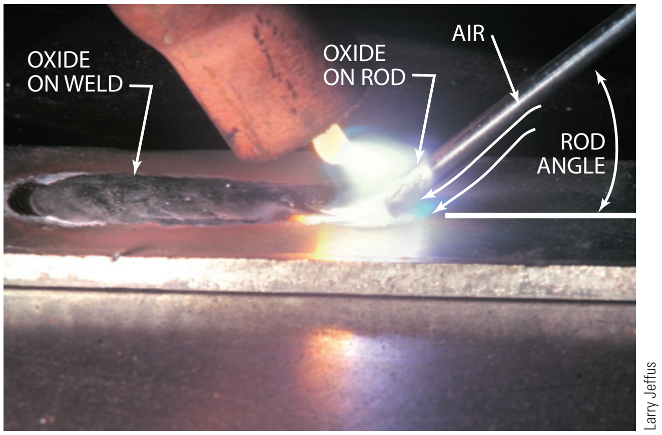

FIGURE 17-7 Too much filler rod angle has caused oxides to be formed on the filler rod end.

TUNGSTEN CONTAMINATION

For new welding students, the most frequently occurring and most time-consuming problem is tungsten **contamination**. The tungsten becomes contaminated when it touches the molten weld pool or when it is touched by the filler metal. When this happens, especially with aluminum, **surface tension** pulls the contamination up onto the hot tungsten, **Figure 17-8**. The extreme heat causes some of the metal to vaporize and form a large, widely scattered **oxide layer**. On aluminum, this layer is black. On iron (steel and stainless steel), this layer is a reddish color.

FIGURE 17-8 Contaminated tungsten.

The contamination caused by the tungsten touching the molten weld pool or filler metal forms a weak weld. On a welding job, both the weld and the tungsten must be cleaned before any more welding can be done. The weld crater must be ground or chiseled to remove the tungsten contamination, and the tungsten end must be reshaped. Extremely tiny tungsten particles will show up if the weld is X-rayed. Failure to remove the contamination properly will result in the failure of the weld.

When starting to weld, the beginning student may save weld practice time by burning off the contamination. On a scrap, usually copper plate, strike an arc using a higher-than-normal amperage setting. The arc will be erratic and discolored at first, but as the contamination vaporizes, the arc will stabilize. Contamination can also be knocked off by quickly flipping the torch head.

CAUTION

This procedure should never be used with heavy contaminations or when a welder is on the job in the field. It is designed only to help the new student in the first few days of training to save time and increase weld production.

CURRENT SETTING

The amperage set on a machine and the actual welding current are often not the same. The amperage indicated on the machine's control is the same as that at the arc only for the following conditions:

- The power to the machine is exactly correct.
- The lead length is very short.
- All cable connections are perfect with zero resistance.
- The arc length is exactly the right length.
- The remote current control is in the full on position.

If any one of these factors changes, then the actual welding amperage will change.

In addition to the difference between indicated and actual welding amperage, there is a more significant difference between amperage and welding power. The welding power, in watts, is based on the formula $W = E \times I$, or volts (E) multiplied by amperes (I) equals watts (W). Thus, the indicated power to a weld from two different types of welding machines set at 100 amperes will vary depending on the voltage of the machine.

The welding machine setting will vary within a range from low to high (cool to hot). The range for one machine may be different from that of another machine. The setting will also be different for various types and sizes of tungstens, polarities, types and thicknesses of metal, joint position or design, and shielding gas used.

A chart, such as the one in **Table 17-1**, and a series of tests can be used to set the lower and upper limits for the

Current and Tungsten Electrode Size	Amperage/Machine Setting				
	Too Low	Low	Good	High	Too High

TABLE 17-1 Sample Chart Used to Record GTA Welding Machine Settings

amperage settings. As students' welding skills improve with practice, they will become familiar with the machine settings so that a table for these settings is no longer needed. In the welding industry, some welders will mark a line on the dial of the machine to help in resetting the machine. If a welder is required to make a number of different machine setups, then a list or chart can be made and taped to the machine. This practice is more professional than marking the machine dials.

EXPERIMENTS

Experiments are designed to help new welders learn some basic skills that will help them troubleshoot welding problems. If you do the experiments listed in this chapter, you will be better able to determine what is causing a problem with your weld. As you learn more about welding, subtle changes will become more noticeable. Even experienced welders make changes in the setup, current, or welding technique as they try to resolve a problem.

Experiment 17-1 will help the welder determine the correct machine settings for the minimum and maximum welding current for the machine used, the types and sizes of tungstens, and the metal types and thicknesses. Most welding will be performed with a medium-range or mid-range machine setting. The exact setting is more important for machines without remote controls. The remote control allows changes in welding current to be made during the welding without having to stop.

EXPERIMENT 17-1

Setting the Welding Current

Using a properly set-up GTA welding machine and torch, proper safety protection, one of each available tungsten size and type, and 16-gauge mild steel 1/8 in. (3 mm) and 1/4 in. (6 mm) thick, you will work with a small group of students to develop a chart of the correct machine current setting for each type and size of tungsten.

Set the machine welding power switch for DCEN (DCSP) and the amperage control to its lowest setting, **Figure 17-9**. Sharpen a point on each tungsten and install one of the smaller diameter tungstens in the GTA torch. Select a nozzle with a 1/2-in. (13-mm) diameter hole and attach it to the torch head. Set the prepurge time to 0 and postpurge time to 10 to 15 sec. Connect the remote control

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FIGURE 17-9 Lower the welding current to zero or as low as possible.

if it is available. Turn on the main power and hold the torch so that it cannot short out. Depress the remote controls to start the shielding gas so the flow rate can be set at 20 cfh (8 L/min). Switch the high frequency to start. All other functions, such as pulse, hot start, slope, and so on, should be in the off position.

Place the piece of 16-gauge sheet metal flat on the welding table. Hold the torch vertically with the tungsten approximately 1/4 in. (6 mm) above the metal. Lower your welding hood and fully depress the remote control. Watch the arc to see if it stabilizes and melts the metal. After a short period of time (15 to 30 sec), stop, raise your hood, and check the plate for a melted spot. If melting occurred, note the size of the spot and depth of penetration, **Figure 17-10**. Increase the amperage setting by 5 or 10 amperes, note the setting on the chart, and repeat the process.

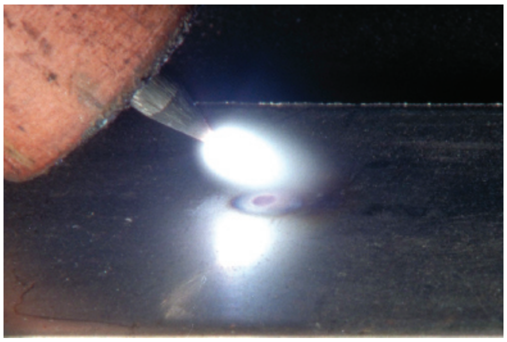

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FIGURE 17-10 Melting first occurring.

After each test, observe and record the results. The important settings to note are:

1. when the tungsten first heats up and the arc stabilizes,
2. when the metal first melts,
3. when 100% penetration of the metal first occurs,
4. when burnthrough first occurs, and
5. when the tungsten starts glowing white hot and/or melts.

The lowest (minimum) acceptable amperage setting is when the molten weld pool first appears on the base metal and the arc is stable. The highest (maximum) amperage setting is when the base metal burnthrough or melting of the tungsten occurs. Any current setting in between the high and low points is within the amperage range for that specific setup.

To establish the range for the next tungsten type or size, repeat the test. After each test, the metal should be cooled to prevent overheating. After each type and size of tungsten has been tested and an operating range established, repeat the procedure using the next thicker metal. Repeat this procedure until you have set up the operating ranges for all of the metals and tungstens you will be using. Turn off the welding machine, shielding gas, and cooling water, and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

GAS FLOW

The gas preflow and postflow times required to protect both the tungsten and the weld depend on the following factors:

- Wind or draft speed
- Nozzle size used
- Tungsten size used
- Amperage
- Joint design
- Welding position
- Type of metal welded

The weld quality can be adversely affected by improper gas flow settings. The lowest possible gas flow rates and the shortest preflow or postflow time can help reduce the cost of welding by saving the expensive shielding gas.

In Experiment 17-2, the minimum and maximum gas flow settings for each nozzle size, tungsten size, and amperage setting will be determined. The chart a welder prepares based on experiments is to improve that welder's skill and welding technique. Charts may differ slightly from one welder to another. As a welder's skill improves, the chart may change. As experience is gained, a welder will learn how to set the gas flow effectively without the need for this chart.

The minimum flow rates and times must be increased to weld in drafty areas or for out-of-position welds. The rates and times can be somewhat lower for tee joints or welds made in tight areas. The maximum flow rates must never be exceeded. Exceeding these flow rates causes weld contamination and increases the rejection rate.

EXPERIMENT 17-2

Setting Gas Flow

Using a properly set-up GTA welding machine and torch, proper safety protection, one of each available tungsten size, metal that is 16 gauge to 1/4 in. (6 mm) thick, and the welding current chart developed in Experiment 17-1, you will work with a small group of other students to make a chart of the minimum and maximum flow rates and times for each nozzle size, tungsten size, and amperage setting. An assistant will also be needed to change and record the flow rate while you work.

Set the machine welding power switch for DCEN (DCSP). Set the amperage to the lowest setting for the size of tungsten used. Set the prepurge time to 0 and postpurge at 20 sec, **Figure 17-11**. Turn on the main power. Switch the high frequency to start. All other functions, such as pulse, hot start, slope, and so on, should be in the off position. With the torch held so that it cannot short out, depress the remote control to start the shielding gas flow and set the flow at 20 cfh (9 L/min).

Starting with the smallest nozzle and tungsten size, strike an arc and establish a molten pool on a piece of metal in the flat position. Watch the molten weld pool and tungsten for signs of oxide formation as another person slowly lowers the gas flow rate. Have that person note this setting (where oxide formation begins), **Figure 17-12**, as the minimum flow rate on the chart next to the nozzle size and

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FIGURE 17-11 Setting the postpurge timer.


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FIGURE 17-12 Oxides forming due to inadequate gas shielding.

Electrode and Nozzle Size	Flow Rate					Postflow Time		
	Too Low	Low	Good	High	Too High	Too Short	OK	Too Long

TABLE 17-2 Sample Chart for Setting Shielding Gas Flow Rate and Time

current setting. Now slowly increase the flow rate until the molten pool starts to be blown back or oxides start forming. This setting should be noted on the chart as the maximum flow rate for this current and nozzle size, **Table 17-2**. Lower the flow to a rate of 2 cfh or 3 cfh (1 L/min or 2 L/min) above the minimum value noted on the chart and then stop the arc. Record the length of time from the point when the arc stops and the tungsten stops glowing as the postflow time. Repeat this test at a medium and then high current setting for this nozzle and tungsten size. When using high current settings, it may be necessary to move the torch or use thicker plate to prevent burnthrough.

Repeat this test procedure with each available nozzle and tungsten size. Stainless steel or aluminum is preferred for this experiment because the oxides are more quickly noticeable than when mild steel is used. If aluminum is used, the welding current must be AC, and the high-frequency switch should be set on continuous.

To establish the minimum preflow time for each nozzle and tungsten size, set the amperage to a medium-high setting. Hold the torch above the metal so that an arc will be instantly started. Set the preflow timer to 0 and the gas flow to just above the minimum value noted on the chart. Quickly strike an arc on metal thin enough to cause a weld pool to form instantly at that power setting. Stop the arc and examine the weld pool and tungsten for oxides. Repeat this procedure, increasing the preflow time until no oxides are formed on either the plate or tungsten. Record this time on the chart as the minimum preflow time. Repeat this test with each available nozzle and tungsten size. Compare your notes with the other students in your group and together complete a chart of the data collected. Turn off the welding machine, shielding gas, and cooling water, and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE WELDS

The practice welds are grouped according to the weld position and type of joint and not by the type of metal. The order in which a person decides to do the welds is that person's choice. It is suggested that the stringer beads be done in each metal and position before the different joints are tried. Each metal has its own characteristics that may make one metal easier for a person to work on than another metal.

Mild steel is inexpensive and requires the least amount of cleaning. Slight changes in the metal have little effect on the welding skill required. Stainless steel is somewhat affected by cleanliness, requiring little preweld cleaning. However, the weld pool shows overheating or poor gas coverage. With aluminum, cleanliness is a critical factor. Oxides on aluminum may prevent the molten weld pool from flowing together. The surface tension helps hold the metal in place, giving excellent bead contour and appearance.

The degree of difficulty a welder encounters with each of these metals depends on the individual's experience. Try each weld with each metal to determine which metal will be easiest to master first. The type of welding machine and materials used will also affect a welder's progress. Practice will help welders overcome any obstacle to their progress.

LOW CARBON AND MILD STEELS

Low carbon and mild steel are two basic steel classifications. These steels are the most common type of steels that a new GTA welding student will experience welding. Carbon is the primary alloy in these classifications of steel, and it ranges from 0.15% or less for low carbon and 0.15% to 0.30% for mild steel. The GTA welding techniques required for welding steels in both classifications are the same. You start with a pointed tungsten, **Figure 17-13**,

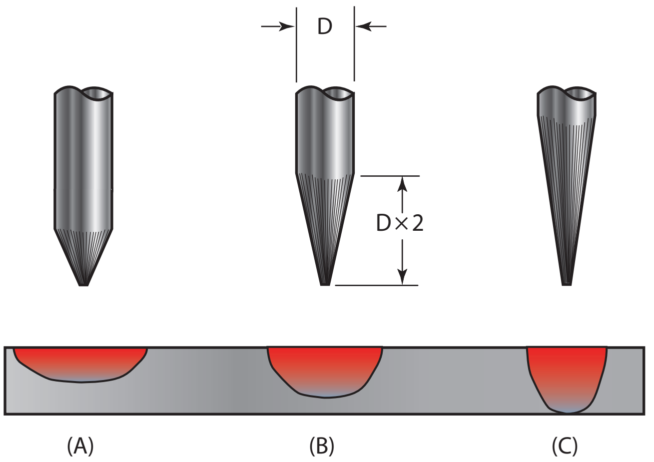

FIGURE 17-13 Tungsten tip shape for mild steel or stainless steel.

SAE No.	Carbon %	AWS Filler Metal No.
Low Carbon		
1006	0.08 max	RG60 or ER70S-3
1008	0.10 max	RG60 or ER70S-3
1010	0.08 to 0.15	RG60 or ER70S-3
Mild Steel		
1015	0.11 to 0.16	RG60 or ER70S-3
1016	0.13 to 0.18	RG60 or ER70S-3
1018	0.15 to 0.20	RG60 or ER70S-3
1020	0.18 to 0.23	RG60 or ER70S-3
1025	0.22 to 0.29	RG60 or ER70S-3

TABLE 17-3 Filler Metals for LowCarbon and Mild Steels

with the welding machine set for DCEN (DCSP) welding current. **Table 17-3** lists the types of filler metal used for both low carbon and mild steels.

During the manufacturing process, sometimes small pockets of primarily carbon dioxide gas become trapped inside low carbon and mild steels. There are only a few molecules of gas trapped inside the microscopic pockets within the steel, so they do not affect the steel strength. During most other types of welding, fluxes on the filler metal capture these gas pockets and they are removed. However, because GTA filler metals do not have fluxes, when these gas pockets become hot during welding, they expand and can sometimes cause weld porosity. You are most likely to see porosity caused by these gases when you are not using a filler metal. Most GTA filler metals have some alloys, called deoxidizers, that can help prevent porosity caused by gases trapped in the base metal. RG45 gas welding rods do not have these deoxidizers and are not recommended for GTA welding.

THINK GREEN

Conserve Filler Metal

It is difficult to use the full length of filler rod. Depending on your skill, the joint type, or metal thickness, there may be from 3 in. to 6 in. (75 mm to 150 mm) of filler rod left as a stub. Welding mild steel stubs together is easier than welding stainless steel and aluminum stubs, but all three can be joined in the welding lab. However, it is not acceptable to join rod stubs in many welding shops that are working to a high standard or code. In this case, too many impurities and oxides might result in a weld failing inspection.

STAINLESS STEEL

The setup and manipulation techniques required for stainless steel are nearly the same as those for low carbon and mild steels, and skills transfer is easy. The major difference is that most welds on steels do not show the effects of contamination as easily as do welds on stainless steels. To make a weld on stainless steel you must do a better job of precleaning the base metal and filler metal; make sure you have adequate shielding gas coverage and do not overheat the weld.

Surface Color	Approximate Temperature at Which Color Is Formed	
	(°F)	(°C)
Light straw	400	(200)
Tan	450	(230)
Brown	525	(275)
Purple	575	(300)
Dark blue	600	(315)
Black	800	(425)

TABLE 17-4 Temperatures at Which Various Colored Oxide Layers Form on Steel

The most common sign that there is a problem with a stainless steel weld is the bead color after the weld. The greater the contamination, the darker the color. The exposure of the weld bead to the atmosphere before it has cooled will also change the bead color. It is impossible, however, to determine the extent of contamination of a weld with only visual inspection. Both light-colored and dark-colored welds may not be free from oxides. Thus, it is desirable to take the time and necessary precautions to make welds that are no darker than dark blue, **Table 17-4**. Welds with only slight oxide layers are better for multiple passes.

Using a low arc current setting with faster travel speeds is important when welding stainless steel because some stainless steels are subject to carbide precipitation. Carbide precipitation, the combining of carbon with chromium, occurs in some stainless steels when they are kept at a temperature between 800°F and 1500°F (625°C and 815°C) for a long time. There are a number of ways of controlling carbide precipitation by adding alloys to the stainless steel or by lowering the percentage of carbon. During welding, special alloy filler metals can be used to control the problem (see Chapter 27), but the most important thing a welder can do is travel fast and use as little welding heat as possible. For more information on controlling carbide precipitation in stainless steel, see Chapter 25.

Black crusty spots may appear on weld beads. These spots are often caused by improper cleaning of the filler rod or failure to keep the end of the rod inside the shielding gas.

Table 17-5 lists some common types of stainless steels and the recommended filler metals; see Chapter 27 for a more complete listing.

AISI No.	AWS Filler No.	AISI No.	AWS Filler No.
303	ER308	310	ER310
304	ER308	316	ER316L
304L	ER308L	316L	ER316L
309	ER309	410	ER410

TABLE 17-5 Filler Metals for Stainless Steels

FIGURE 17-14 Tungsten tip shape for aluminum.

AISI No.	AWS Filler No.	AISI No.	AWS Filler No.
1100	ER1100	3004	ER4043
3003	ER4043	6061	ER4043

TABLE 17-6 Filler Metals for Aluminum Alloys

ALUMINUM

Aluminum is GTA welded using a rounded tip tungsten, **Figure 17-14**, with the welding machine set for ACHF welding current. The alternating current provides good arc cleaning, and the continuous high frequency restarts the arc as the current changes direction.

The molten aluminum weld pool has high surface tension, which allows large weld beads to be controlled easily. **Table 17-6** lists some basic types of filler metal used for aluminum welding; see Chapter 27 for a more complete listing.

The high thermal conductivity of the metal may make starting a weld on thick sections difficult without first preheating the base metal. In most cases, the preheat temperature is approximately 300°F (150°C) but will vary depending on metal thickness and alloy type. Specific preheat temperatures are available from the metal supplier.

The processes of cleaning and keeping the metal clean take a lot of time. Removal of the oxide layer is easy using a chemical or mechanical method. Ten minutes after cleaning, however, the oxide layer may again be thick enough to require recleaning. The oxide that forms reduces the ability of the weld pool to flow together. Keep your hands and gloves clean and oil-free so the base metal or filler rods do not become recontaminated.

Although aluminum resists oxidation at room temperature, it rapidly oxidizes at welding temperatures. If the filler rod is not kept inside the shielding gas, then it will quickly oxidize; however, because of the low melting temperature of the filler rod, the end will melt before it is added to the weld pool if it is held too closely to the arc, **Figure 17-15** and **Figure 17-16**.

METAL PREPARATION

Both the base metal and the filler metal used in the GTAW process must be thoroughly cleaned before welding. Contamination left on the metal will be deposited in the weld because there is no flux to remove it. Oxides, oils, and dirt are the most common types of contaminants. They can be removed mechanically or chemically. Mechanical

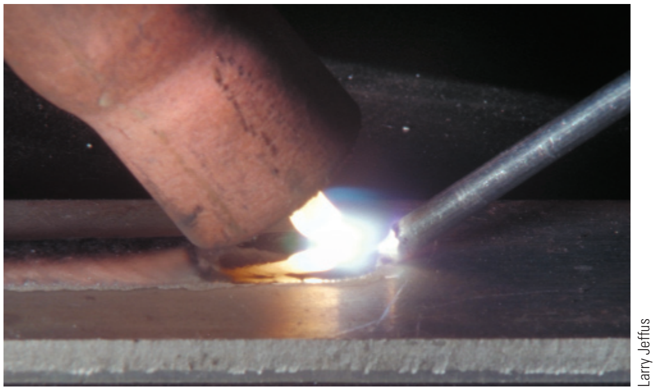

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FIGURE 17-15 Aluminum filler being correctly added to the molten weld pool.

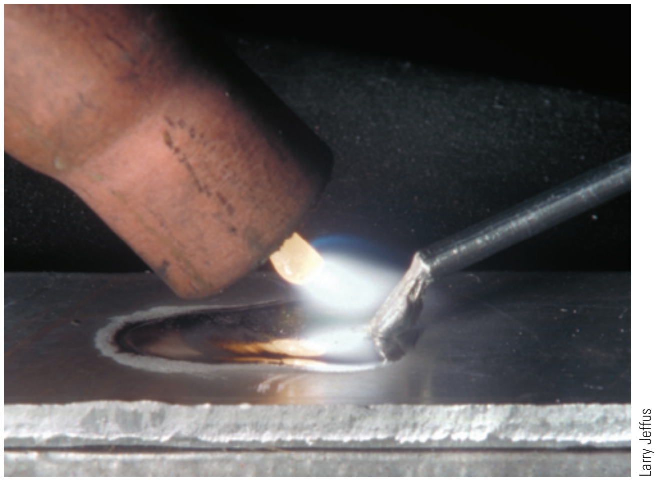

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FIGURE 17-16 Filler rod being melted before it is added to the molten pool.

metal cleaning may be done by grinding, wire brushing, scraping, machining, sand blasting, or filing. Chemical cleaning may be done by using acids, alkalies, solvents, or detergents.

CAUTION

The manufacturer's recommendations for using these products must be followed. Failure to do so may result in chemical burns, fires, fumes, or other safety hazards that could lead to serious injury. If anyone comes in contact with any chemicals, immediately refer to the material safety data sheet (MSDS) for the proper corrective action.

PRACTICE 17-1

Stringer Beads, Flat Position, on Mild Steel

Using a properly set-up and adjusted GTA welding machine on DCEN, proper safety protection, and one or more pieces

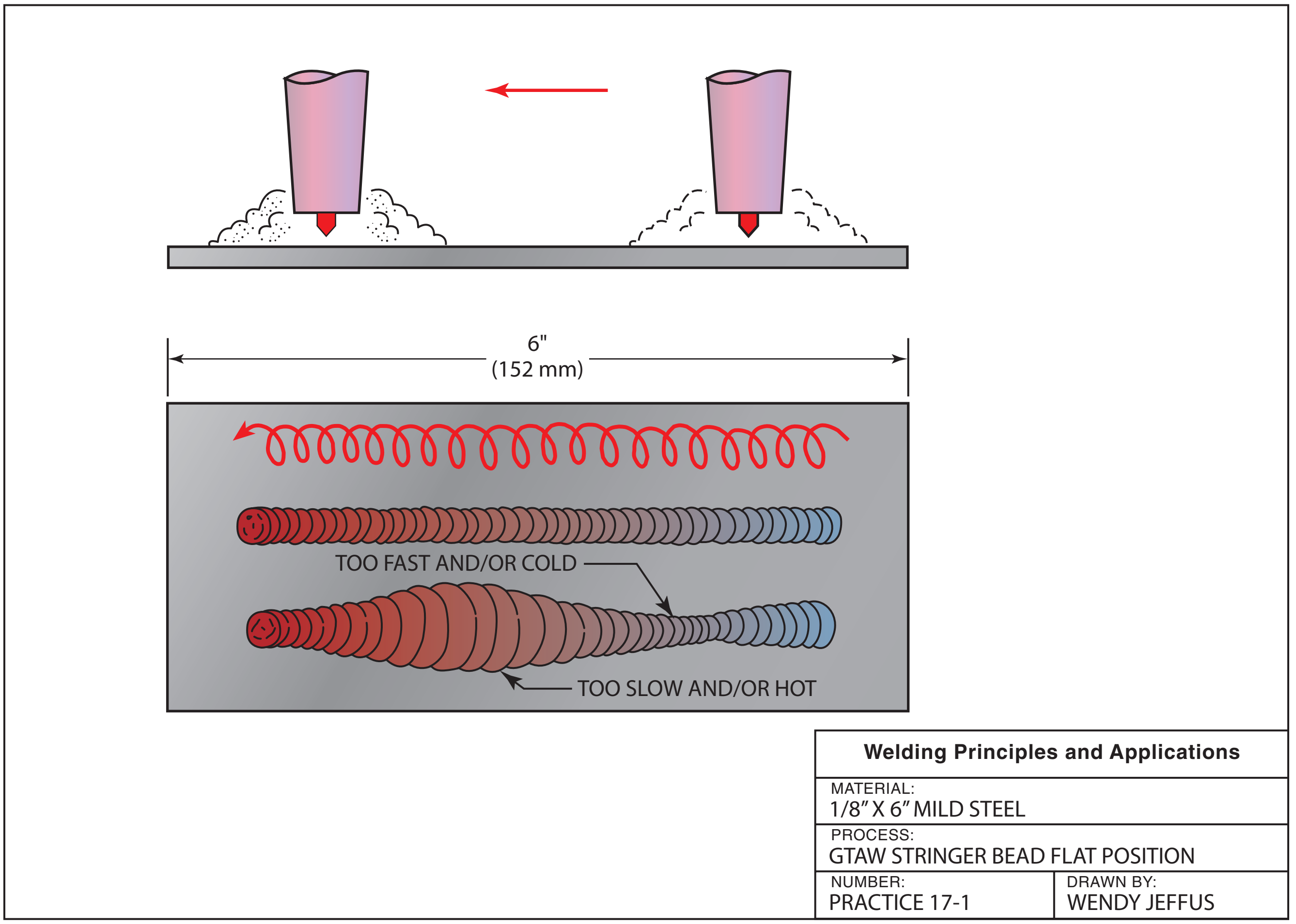

FIGURE 17-17 Surfacing weld in the flat position.

of mild steel 6 in. (152 mm) long, 16 gauge, and 1/8 in. (3 mm) thick, you will push a weld pool in a straight line down the plate, **Figure 17-17**. Maintain uniform weld pool size and penetration.

- Starting at one end of the piece of metal that is 1/8 in. (3 mm) thick, hold the torch as close as possible to a 90° angle.
- Lower your hood, strike an arc, and establish a weld pool.
- Move the torch in a stepping or circular oscillation pattern down the plate toward the other end, **Figure 17-18**.
- If the size of the weld pool changes, speed up or slow down the travel rate to keep the weld pool the same size for the entire length of the plate.

The ability to maintain uniformity in width and keep a straight line increases as you are able to see more than just the weld pool. As your skill improves, you will relax and your field of vision will increase.

Repeat the process using both thicknesses of metal until you can consistently make the weld bead visually defect-free. Turn off the welding machine, shielding gas, and cooling water, and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

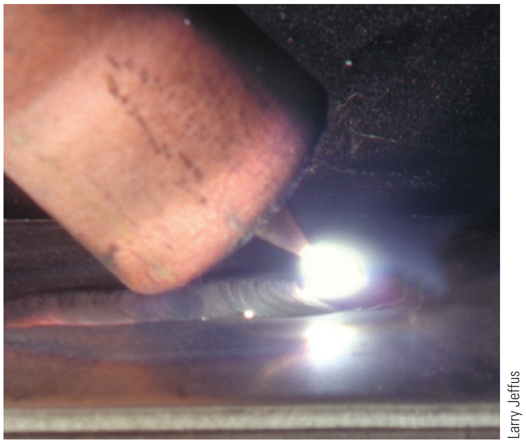

FIGURE 17-18 Surfacing weld.

PRACTICE 17-2

Stringer Beads, Flat Position, on Stainless Steel

Using the same equipment and material thicknesses as listed in Practice 17-1 and one or more pieces of stainless steel 6 in. (152 mm) long and 1/4 in. (6 mm) thick, you will push a molten weld pool in a straight line down the plate, keeping the width and penetration uniform.

To keep the formation of oxides on the bead to a minimum, a **chill plate** (a thick piece of metal used to absorb heat) may be required. Another method is to make the bead using as low of a heat input as possible. When the weld is finished, the weld bead should be no darker than dark blue.

Repeat the process using both thicknesses of metal until you can consistently make the weld bead visually defect-free. Turn off the welding machine, shielding gas, and cooling water, and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 17-3

Stringer Beads, Flat Position, on Aluminum

Using the same equipment, setup for AC, and procedure as listed in Practice 17-1 and one or more pieces of aluminum 6 in. (152 mm) and 1/16 in. (2 mm) long, 1/8 in. (3 mm), and 1/4 in. (6 mm) thick, you will push a weld pool in a straight line, maintaining uniform width and penetration for the length of the plate.

A high current setting will allow faster travel speeds. The faster speed helps control excessive penetration. Hot cracking may occur on some types of aluminum after a surfacing weld. This is not normally a problem when filler metal is added. If hot cracking occurs during this practice, do not be concerned.

Repeat the process using all thicknesses of metal until you can consistently make the weld bead visually defect free. Turn off the welding machine, shielding gas, and cooling water, and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 17-4

Flat Position, Using Mild Steel, Stainless Steel, and Aluminum

For this practice, you will need a properly set-up and adjusted GTA welding machine, proper safety protection, filler rods 36 in. (0.9 m) × 1/16 in. (2 mm) long, 3/32 in. (2.4 mm), and 1/8 in. (3 mm) in diameter, one or more pieces of mild steel, stainless steel, and aluminum, 6 in. (152 mm) long × 1/16 in. (2 mm) and 1/8 in. (3 mm) thick, and aluminum plate 1/4 in. (6 mm) thick, **Table 17-7**, **Table 17-8**, and **Table 17-9**. In this practice, you will make a straight stringer bead, 6 in. (152 mm) long, that is uniform in width, reinforcement, and penetration, **Figure 17-19**. Use DCEN current on the steel and AC current on the aluminum.

Starting with the metal that is 1/8 in. (3 mm) thick and the filler rod with a 3/32-in. (2.4-mm) diameter, strike an arc and establish a weld pool, **Figure 17-20**. Move the torch in a circle as in the practice beading. When the torch is on one side, add filler rod to the other side of the molten weld pool, **Figure 17-21A** and **B**. The end of the rod can be held lightly in the leading edge of the molten weld pool, or it can be dipped into the molten weld pool. If you are using the dipping method, be sure not to allow the tip to melt and drip into the weld pool, **Figure 17-22**. Change to another size filler rod and determine its effect on the weld pool.

Maintain a smooth and uniform rhythm as filler metal is added. This will help to keep the bead uniform. Vary the rhythms to determine which one is easiest for you.

Tungsten Electrode			Welding Power			Shielding Gas		Nozzle	Filler Metal	
Type	Size	Tip	Amps	Current	HF	Type	Flow	Size	Type	Size
EWTh-1 or EWTh-2	1/16″ (2 mm)	Point	50 to 100	DCEN DCSP	Start or auto	Argon	16 cfh 7 L/min	3/8″ (10 mm)	RG60 or ER70S-3	1/16″— 3/32″ (2-2.4 mm)
EWTh-1 or EWTh-2	3/32″ (2.4 mm)	Point	70 to 150	DCEN DCSP	Start or auto	Argon	16 cfh 7 L/min	3/8″ (10 mm)	RG60 or ER70S-3	1/16″— 3/32″ (2-2.4 mm)
EWTh-1 or EWTh-2	1/8″ (3 mm)	Point	90 to 250	DCEN DCSP	Start or auto	Argon	20 cfh 9 L/min	1/2″ (13 mm)	RG60 or ER70S-3	3/32″— 1/8″ (2.4 - 3 mm)

TABLE 17-7 Suggested Setting for GTA Welding of Mild Steel

Tungsten Electrode			Welding Power			Shielding Gas		Nozzle	Filler Metal	
Type	Size	Tip	Amps	Current	HF	Type	Flow	Size	Type	Size
EWTh-1 or EWTh-2	1/16″ (2 mm)	Point	70 to 100	DCEN DCSP	Start or auto	Argon	16 cfh 7 L/min	3/8″ (10 mm)	ER308 or ER316	1/16″— 3/32″ (2-2.4 mm)
EWTh-1 or EWTh-2	3/32″ (2.4 mm)	Point	70 to 150	DCEN DCSP	Start or auto	Argon	16 cfh 7 L/min	3/8″ (10 mm)	ER308 or ER316	1/16″— 3/32″ (2-2.4 mm)
EWTh-1 or EWTh-2	1/8″ (3 mm)	Point	90 to 250	DCEN DCSP	Start or auto	Argon	20 cfh 9 L/min	1/2″ (13 mm)	ER308 or ER316	3/32″— 1/8″ (2.4-3 mm)

TABLE 17-8 Suggested Setting for GTA Welding of Stainless Steel

Tungsten Electrode			Welding Power			Shielding Gas		Nozzle	Filler Metal	
Type	Size	Tip	Amps	Current	HF	Type	Flow	Size	Type	Size
EWP or EWZr	1/16″	Round 2 mm	50 to 90	AC	Continues or on	Argon	17 cfh 8 L/min	7/16″ (11 mm)	ER1100 or ER4043	1/16″— 3/32″ (2-2.4 mm)
EWP or EWZr	3/32″	Round 2.4 mm	80 to 130	AC	Continues or on	Argon	20 cfh 9 L/min	1/2″ (13 mm)	ER1100 or ER4043	1/16″— 3/32″ (2-2.4 mm)
EWP or EWZr	1/8″	Round 3 mm	100 to 200	AC	Continues or on	Argon	20 cfh 9 L/min	5/8″ (16 mm)	ER1100 or ER4043	3/32″— 1/8″ (2.4 - 3 mm)

TABLE 17-9 Suggested Setting for GTA Welding of Aluminum

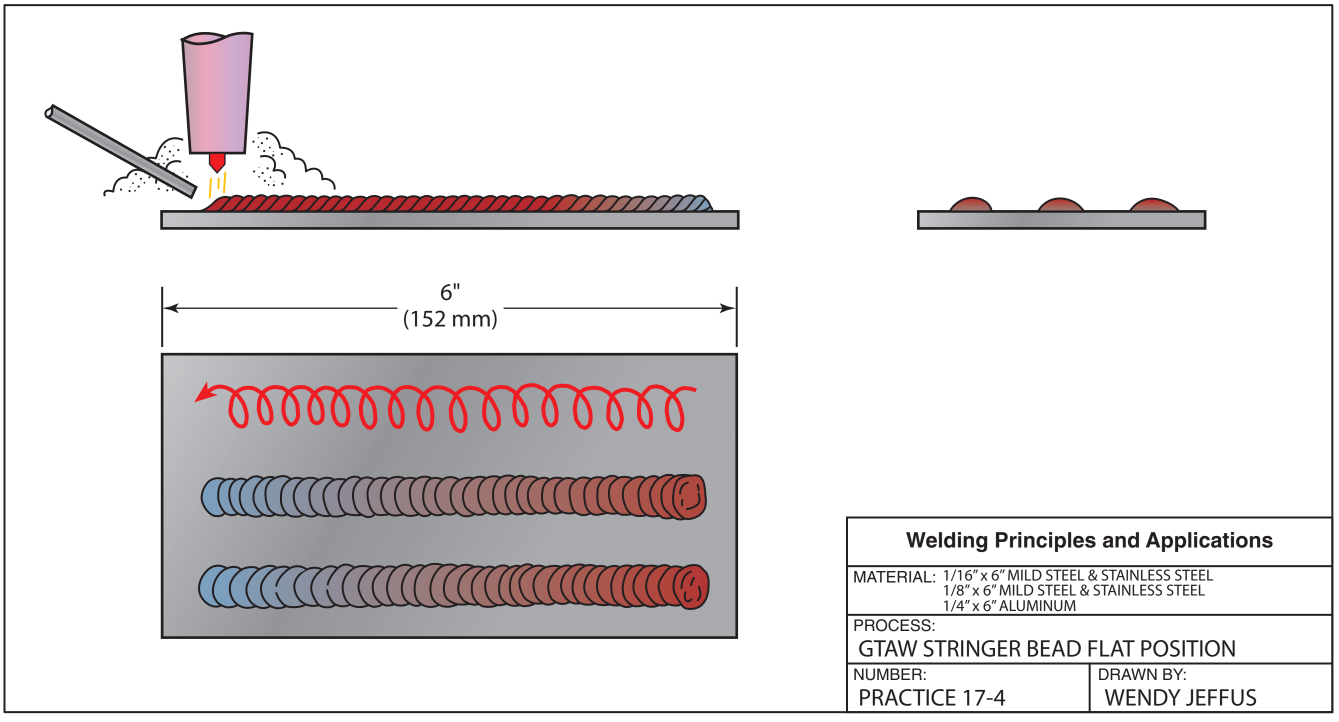

FIGURE 17-19 Stringer beads in the flat position.

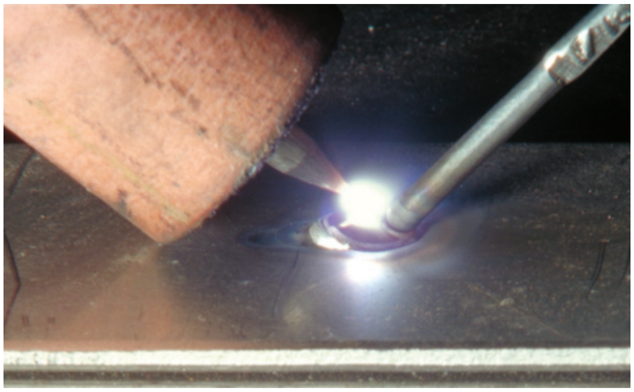

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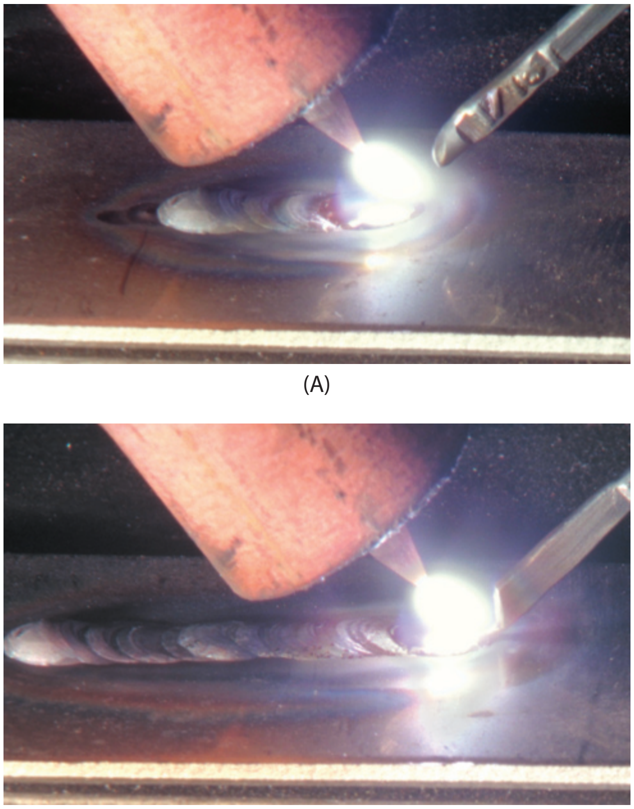
FIGURE 17-20 Establish a molten weld pool and dip the filler rod into it.



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(A)

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(B)

FIGURE 17-21 Note the difference in the weld produced when different sizes of filler rods are used.

If the rod sticks, move the torch toward the rod until it melts free.

When the full 6-in. (152-mm)-long weld bead is completed, cool and inspect it for uniformity and defects. Repeat the process using all thicknesses of metal until you can consistently make the weld visually defect free. Turn off the welding machine, shielding gas, and cooling water, and clean your work area when you are finished welding.

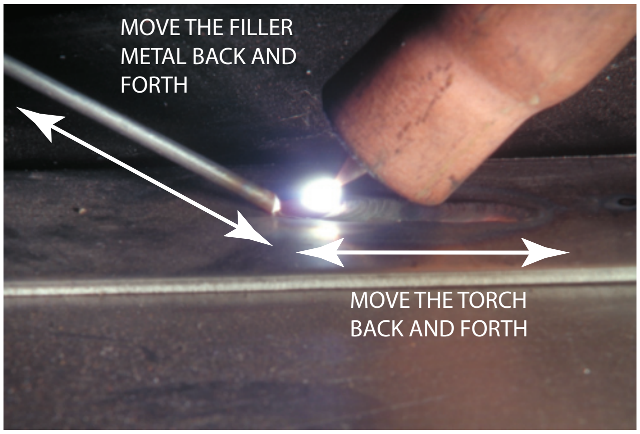

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FIGURE 17-22 Move the electrode back as the filler rod is added.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 17-5

Outside Corner Joint, 1G Position, Using Mild Steel, Stainless Steel, and Aluminum

Using the same equipment and materials as listed in Practice 17-4, weld an outside corner joint in the flat position, **Figure 17-23**.

- Place one of the pieces of metal flat on the table and hold or brace the other piece of metal horizontally on it.
- Tack weld both ends of the plates together, **Figure 17-24**.
- Set up the plates and add two or three more tack welds on the joint as required, **Figure 17-25**.
- Starting at one end, make a uniform weld, adding filler metal as needed. In **Figure 17-26**, note the metal areas that are precleaned before the weld is made.

Repeat each weld as needed until all are mastered. Turn off the welding machine, shielding gas, and cooling water, and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 17-6

Butt Joint, 1G Position, Using Mild Steel, Stainless Steel, and Aluminum

Using the same equipment and materials as listed in Practice 17-4, you will weld a butt joint in the flat position, **Figure 17-27**.

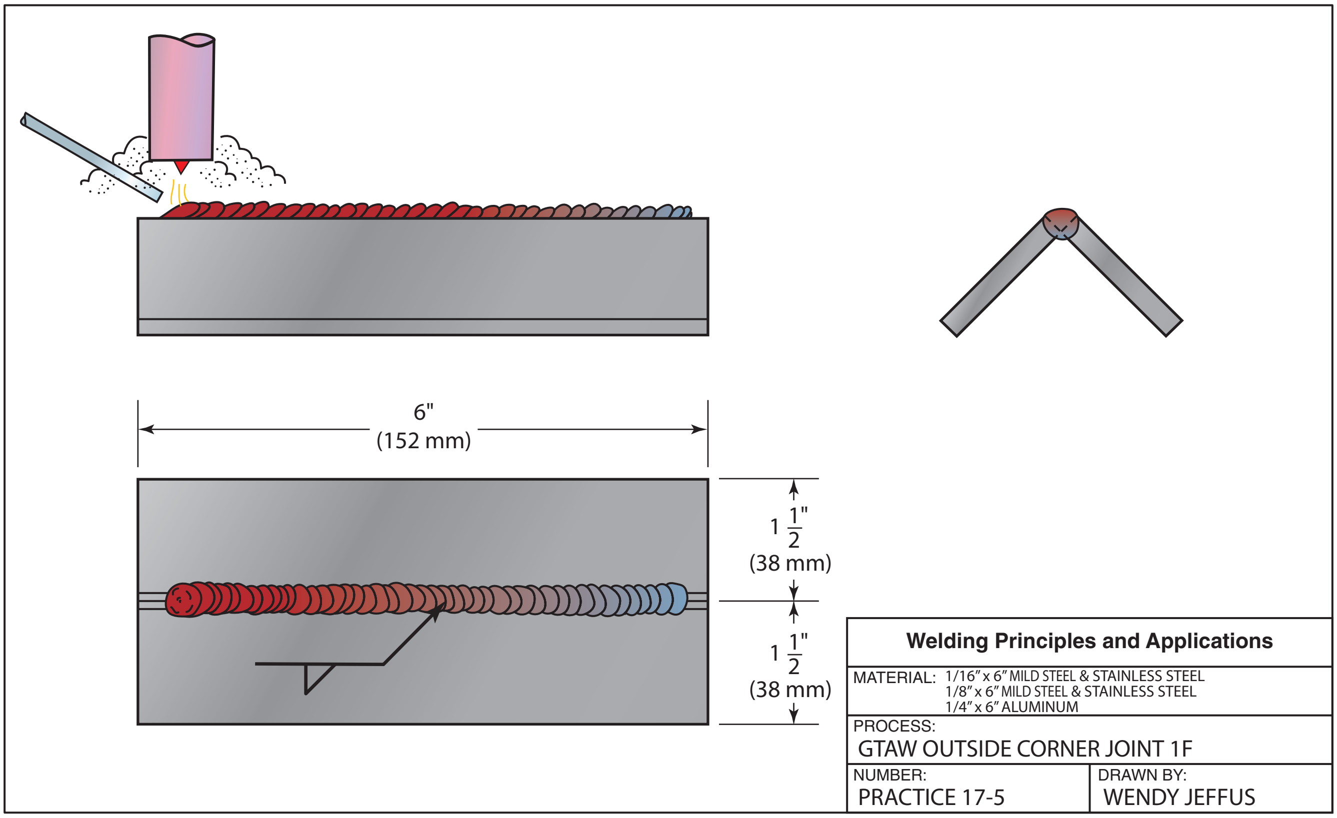

FIGURE 17-23 Outside corner joint in the flat position.

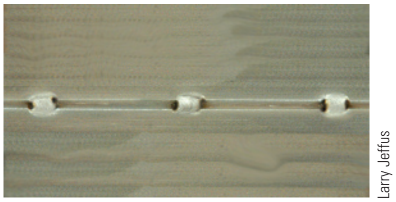

FIGURE 17-24 Tack weld. Note the good fusion at the start and crater fill at the end.

FIGURE 17-25 Outside corner tack welded together.

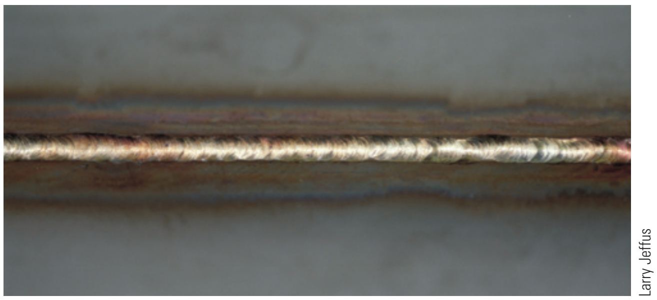

FIGURE 17-26 Outside corner joint. Note precleaning along weld.

Place the metal flat on the table and tack weld both ends together, **Figure 17-28**. Two or three additional tack welds can be made along the joint as needed. Starting at one end, make a uniform weld along the joint. Add filler metal as required to make a uniform weld.

Repeat the process using all thicknesses of metal until you can consistently make the weld visually defect-free. Turn off the welding machine, shielding gas, and cooling water, and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 17-7

Butt Joint, 1G Position, with Minimum Distortion, Using Mild Steel, Stainless Steel, and Aluminum

Using the same equipment and materials as listed in Practice 17-4, you will weld a flat butt joint while controlling both distortion and penetration, **Figure 17-29**.

Tack weld the plates together as shown in **Figure 17-30**. Using a back-stepping weld sequence, make a series of welds approximately 1 in. (25 mm) long along the joint. Be sure to fill each weld crater adequately to reduce crater cracking.

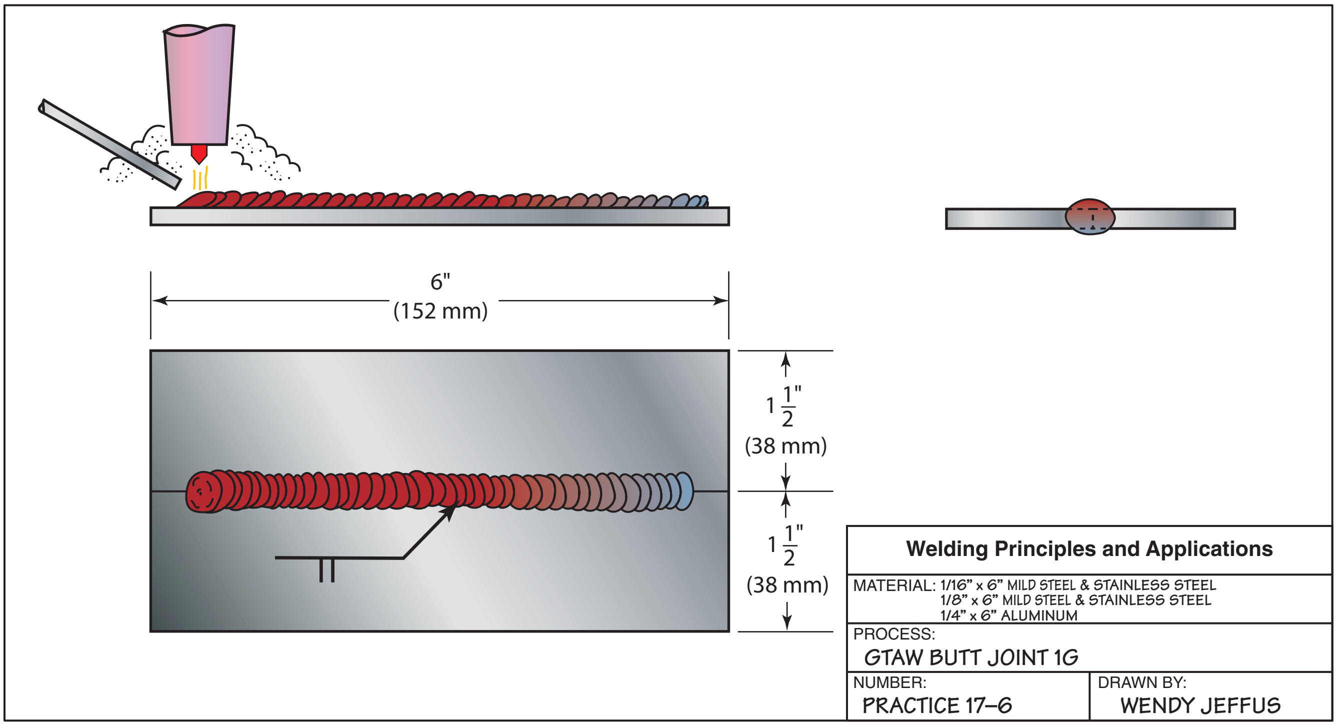

FIGURE 17-27 Square butt joint in the flat position.

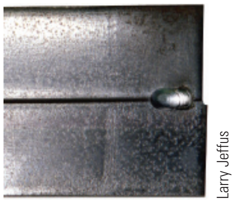

FIGURE 17-28 Tack weld on butt joint.

Repeat the process using all thicknesses of metal until you can consistently make the weld visually defect-free. Turn off the welding machine, shielding gas, and cooling water, and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

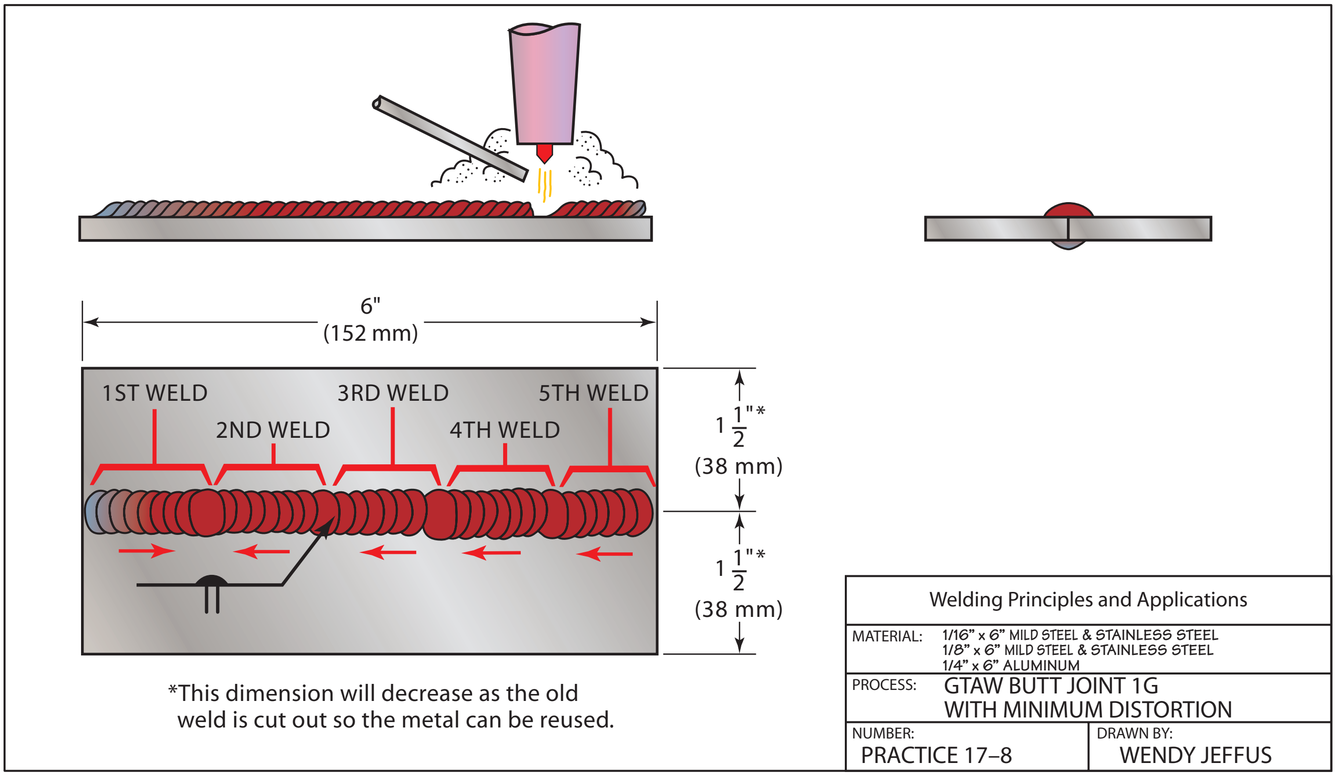

FIGURE 17-29 Square butt joint in the flat position with minimum distortion.

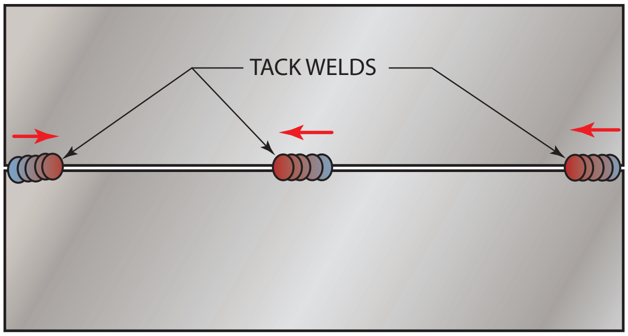

FIGURE 17-30 Tack welds on a butt joint.

PRACTICE 17-8

Lap Joint, 1F Position, Using Mild Steel, Stainless Steel, and Aluminum

Using the same equipment and materials as listed in Practice 17-4, you will weld a lap joint in the flat position, **Figure 17-31**.

Place the two pieces of metal flat on the table with an overlap of 1/4 in. (6 mm) to 3/8 in. (10 mm). Hold the pieces of metal tightly together and tack weld them as shown in **Figure 17-32** and **Figure 17-33**. Starting at one end, make a uniform fillet weld along the joint. Both sides of the joint can be welded.

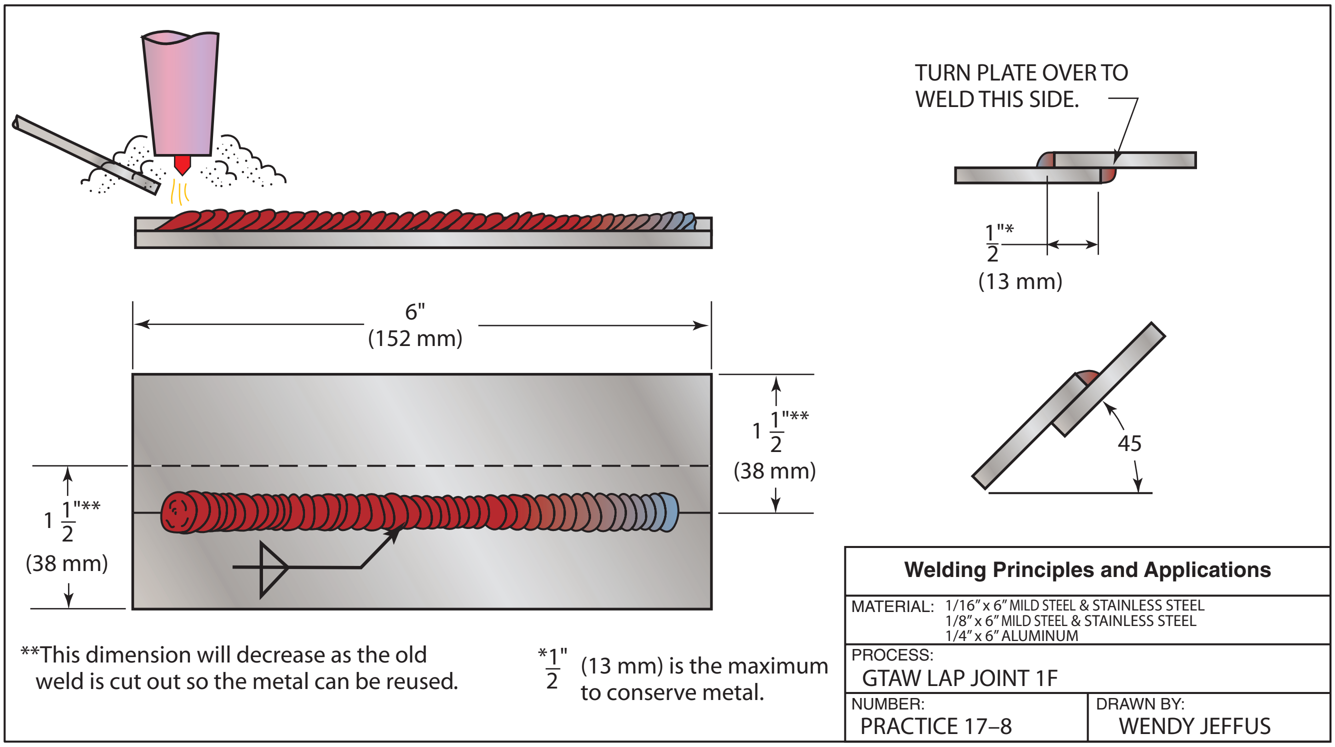

FIGURE 17-31 Lap joint in the flat position.

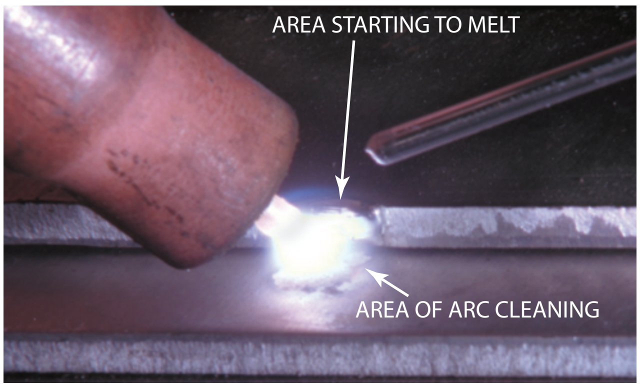

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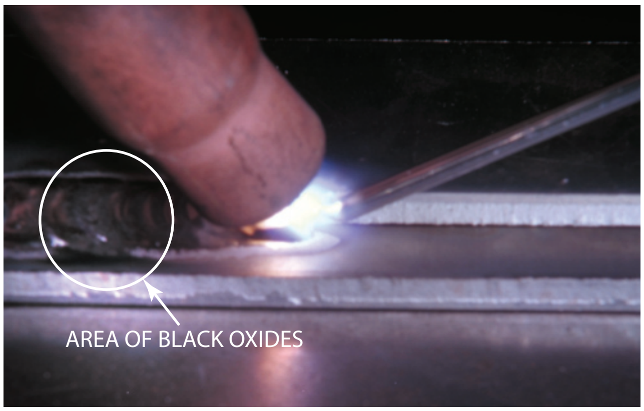
FIGURE 17-32 Be sure both the top and bottom pieces are melted before adding filler metal.



Larry Jeffus

FIGURE 17-33 Oxides form during tack welding. Do not complete the tack welds. These oxides will become part of the finished weld if the tack is completed.

Repeat the process using all thicknesses of metal until you can consistently make the weld visually defect-free. Turn off the welding machine, shielding gas, and cooling water, and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 17-9

Tee Joint, 1F Position, Using Mild Steel, Stainless Steel, and Aluminum

Using the same equipment and materials as listed in Practice 17-4, you will weld a tee joint in the flat position, **Figure 17-34**.

Place one of the pieces of metal flat on the table and hold or brace the other piece of metal horizontally on it. Tack weld both ends of the plates together, **Figure 17-35**. Set up the plates in the flat position and add two or three more tack welds to the joint as required, **Figure 17-36**.

On the metal that is 1/16 in. (1.5 mm) thick, it may not be possible to weld both sides, but on thicker material a fillet weld can usually be made on both sides. The exception to this is if carbide precipitation occurs on the stainless steel during welding.

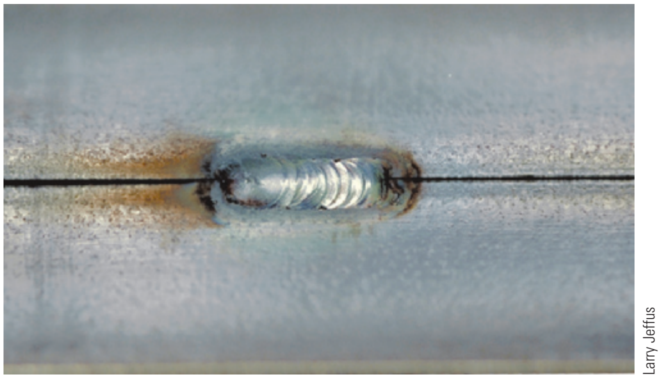


FIGURE 17-35 Tack weld on a tee joint.

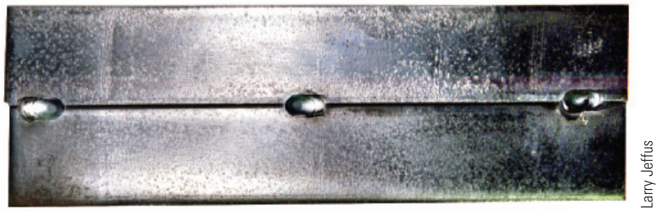


FIGURE 17-36 Keep the tack welds small so that they will not affect the weld.

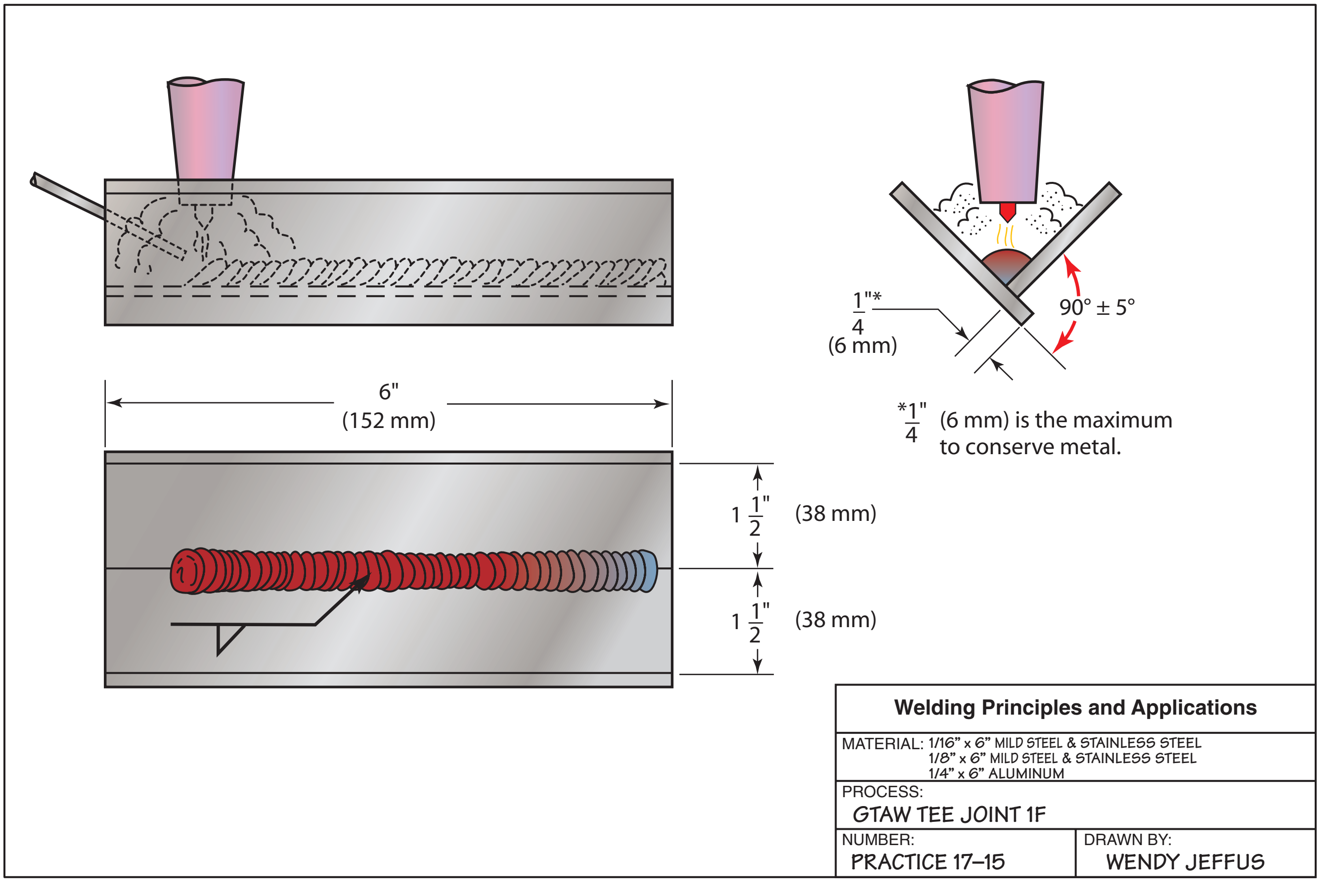


FIGURE 17-34 Tee joint in the flat position.

Starting at one end, make a uniform weld, adding filler metal as needed. Repeat the process using all thicknesses of metal until you can consistently make the weld visually defect-free. Turn off the welding machine, shielding gas, and cooling water, and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

THINK GREEN

Recycle Weld Coupon

Mild steel weld coupons can have the welds removed using an OFC torch, but welds on stainless and aluminum coupons will have to be cut out with a PAC torch. Cut the plate as close as possible to the weld, for example, on a tee joint cut the vertical part as shown in **Figure 17-37**.

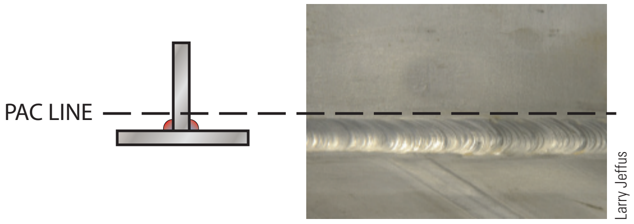


FIGURE 17-37 Recycle weld test plates when possible.

PRACTICE 17-10

Stringer Bead at a 45° Vertical Angle, Using Mild Steel, Stainless Steel, and Aluminum

Using the same equipment and materials as listed in Practice 17-4, you will make a stringer bead in the vertical up position.

- Starting at the bottom and welding in an upward direction, add the filler metal to the top edge of the weld pool and move the torch in a circle or "C" pattern, **Figure 17-38**. If the weld pool size starts to increase, then the "C" pattern can be increased in length or the power can be decreased.
- Watch the weld pool and establish a rhythm of torch movement and addition of rod to keep the weld uniform.

Repeat the process using all thicknesses of metal until you can consistently make the weld visually defect-free. Turn off the welding machine, shielding gas, and cooling water, and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 17-11

Stringer Bead, 3G Position, Using Mild Steel, Stainless Steel, and Aluminum

Repeat Practice 17-13. Gradually increase the angle as you develop skill until the weld is being made in the vertical up

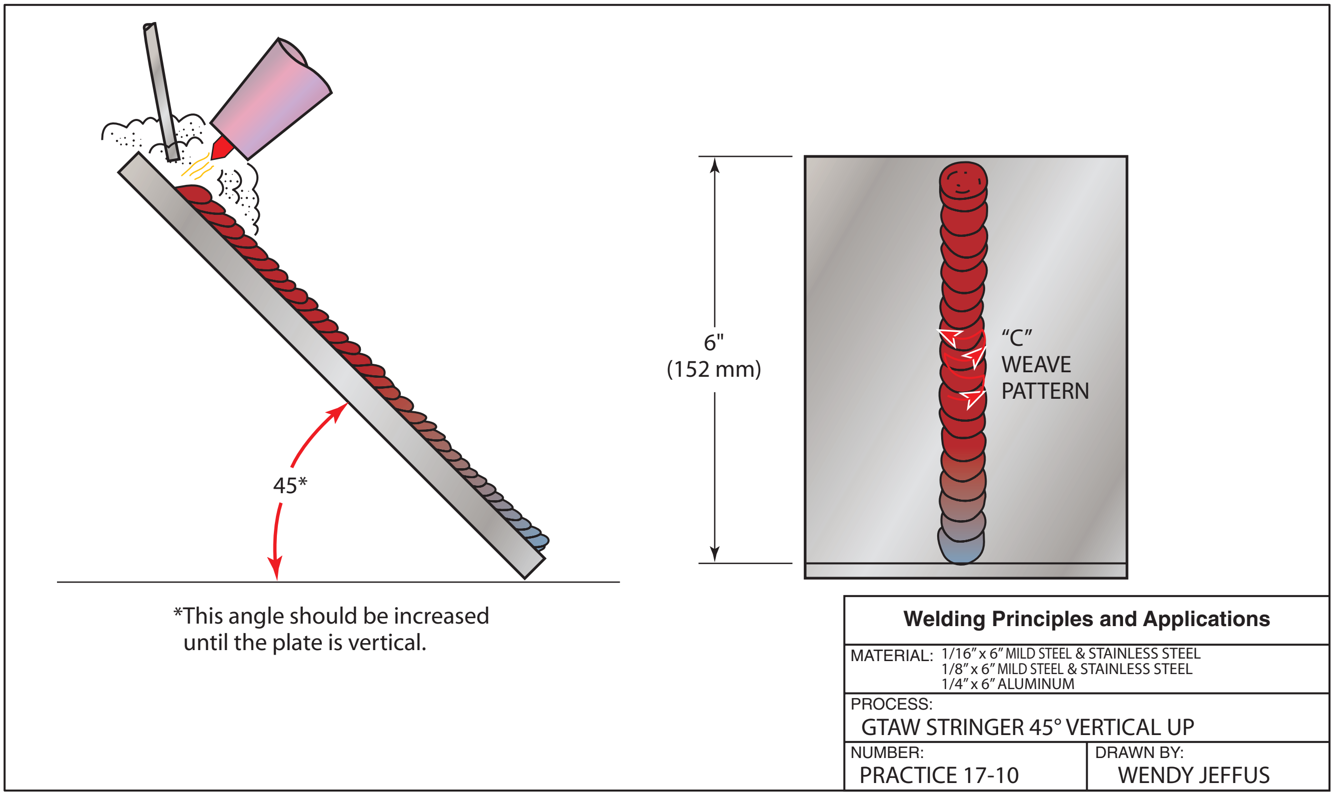


FIGURE 17-38 45° vertical up stringer bead.

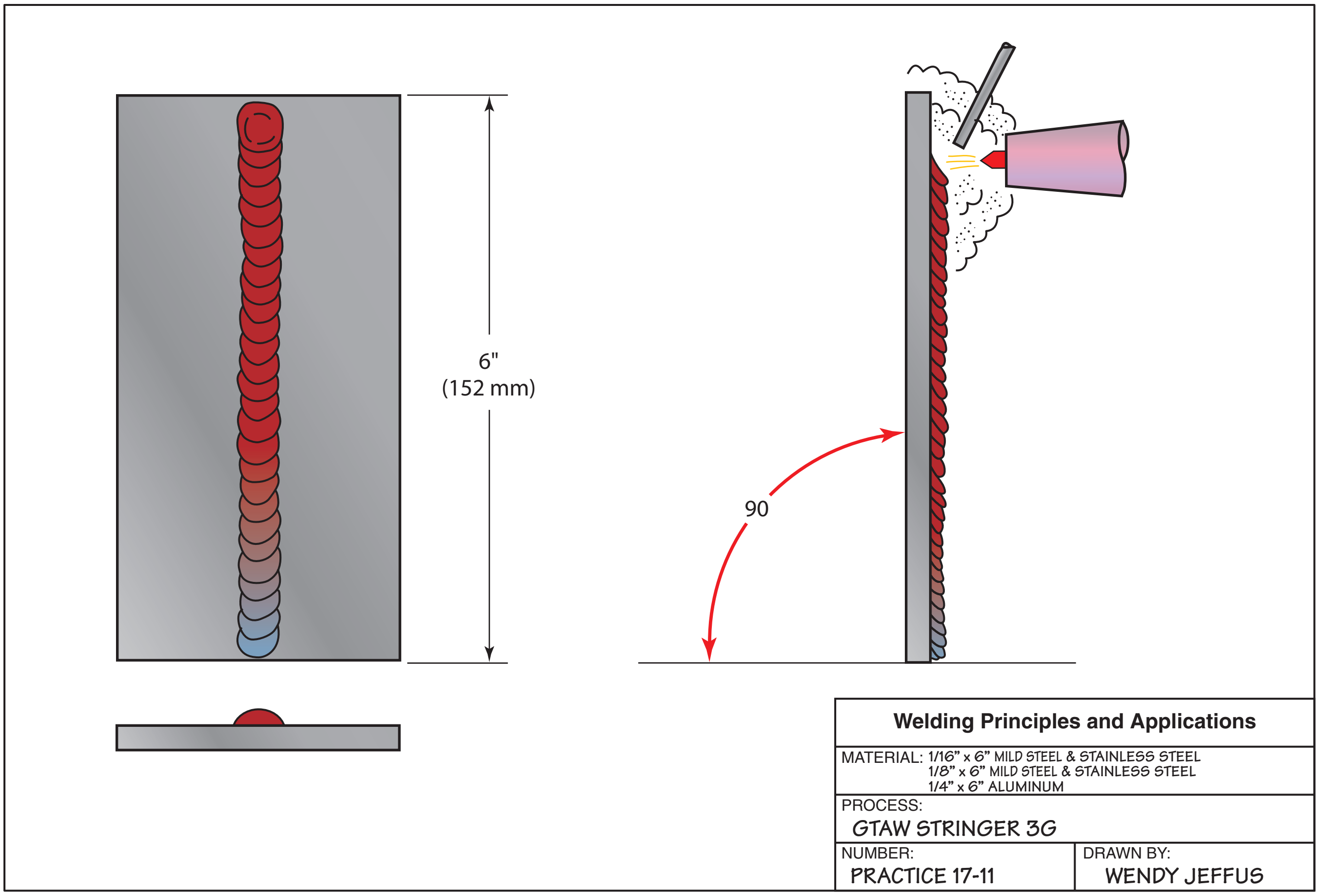


FIGURE 17-39 Vertical up 3G stringer bead.

position, **Figure 17-39**. Repeat the process using all thicknesses of metal until you can consistently make the weld visually defect-free. Turn off the welding machine, shielding gas, and cooling water, and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 17-12

Butt Joint at a 45° Vertical Angle, Using Mild Steel, Stainless Steel, and Aluminum

Using the same equipment and materials as listed in Practice 17-4, you will weld a butt joint in the vertical up position.

After tack welding the plates together, start the weld at the bottom and weld in an upward direction. The same rhythmic torch and rod movement practiced for the 45° stringer bead should be used to control the weld, **Figure 17-40**.

Repeat the process using all thicknesses of metal until you can consistently make the weld visually defect-free. Turn off the welding machine, shielding gas, and cooling water, and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 17-13

Butt Joint, 3G Position, Using Mild Steel, Stainless Steel, and Aluminum

Repeat Practice 17-12. Gradually increase the plate angle after each weld. As you develop skill, continue increasing the angle until the weld is being made in the vertical up position, **Figure 17-41**. Repeat the process using all thicknesses of metal until you can consistently make the weld visually defect-free. Turn off the welding machine, shielding gas, and cooling water, and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 16-14

Lap Joint at a 45° Vertical Angle, Using Mild Steel, Stainless Steel, and Aluminum

Using the same equipment and materials as listed in Practice 17-4, you will make a vertical up fillet weld on a lap joint.

After tack welding the plates together, start the weld at the bottom and weld in an upward direction. It is important to maintain a uniform weld rhythm so that a

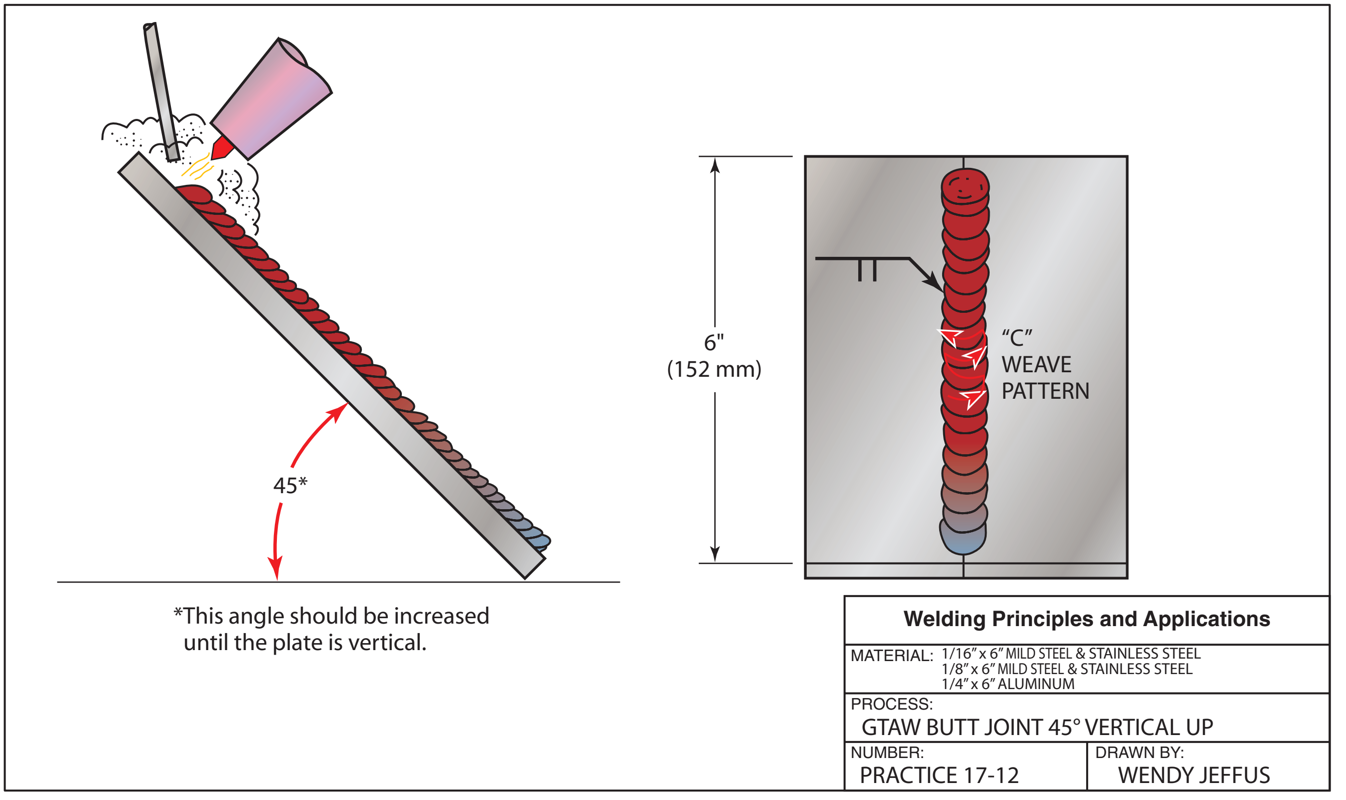


FIGURE 17-40 45° vertical up butt joint.

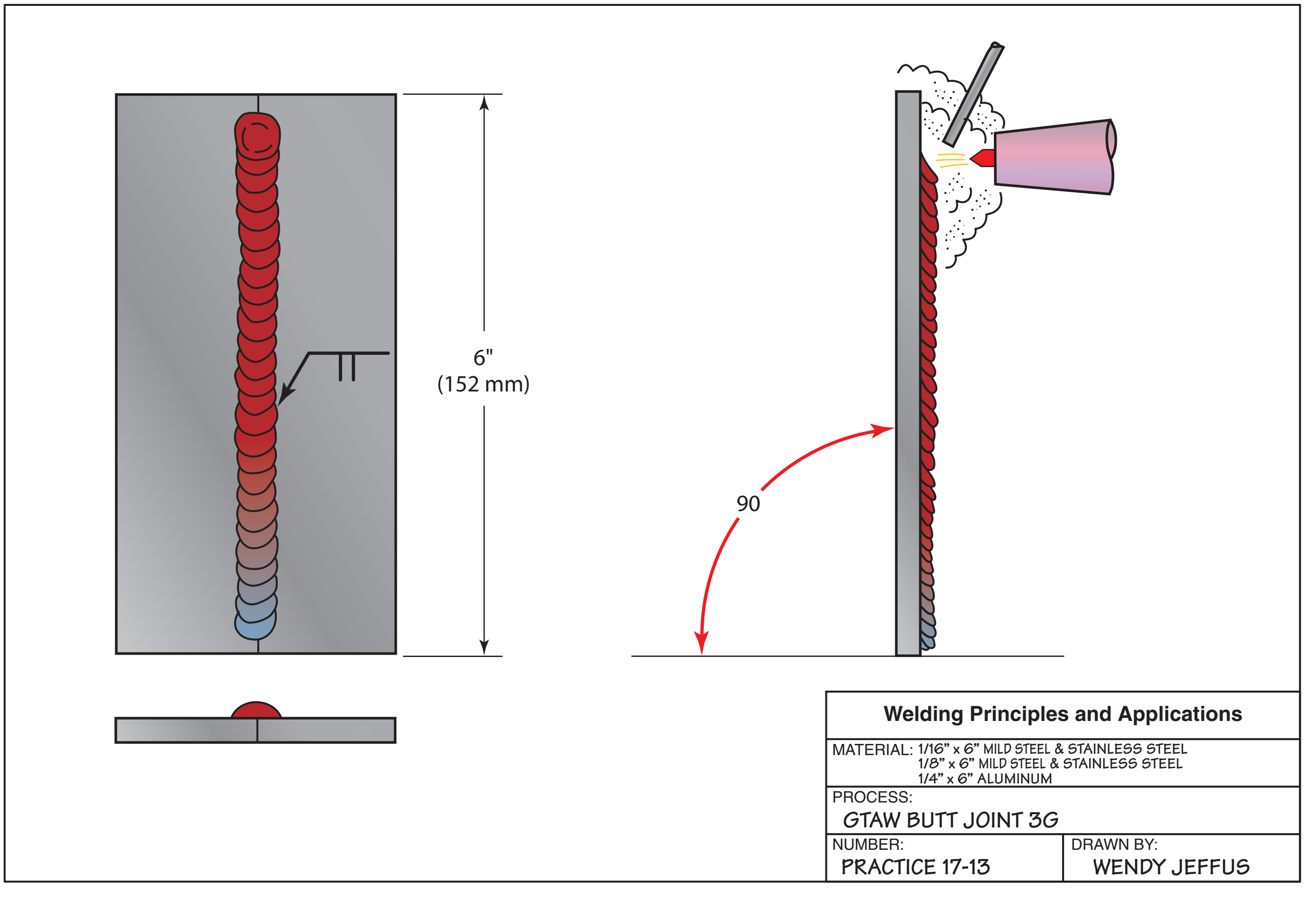


FIGURE 17-41 Vertical up 3G position butt joint.

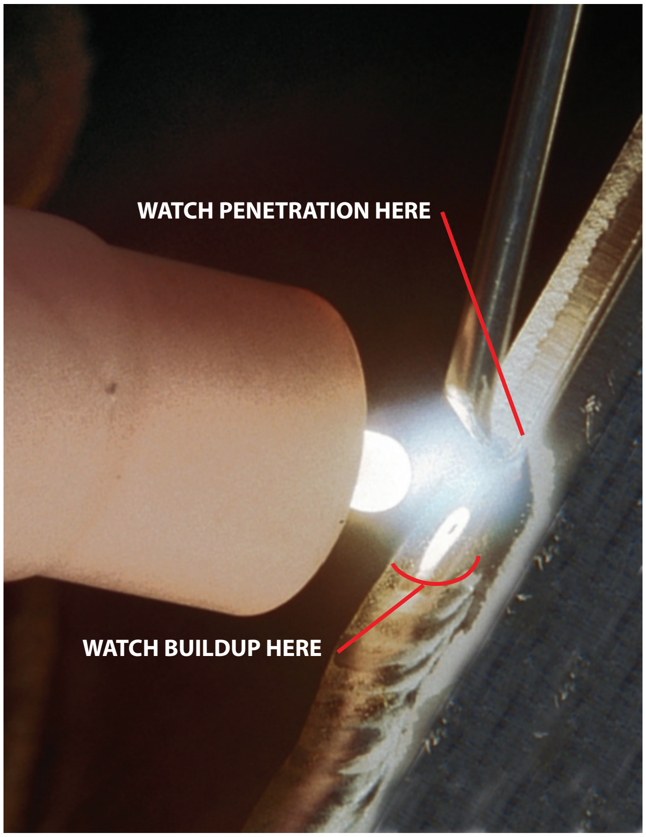


FIGURE 17-42 Vertical up lap joint.

nice-looking weld bead is formed. It may be necessary to move the torch in and around the base of the weld pool to ensure adequate root fusion, **Figure 17-42**. The filler metal should be added along the top edge of the weld pool near the top plate.

Repeat the process using all thicknesses of metal until you can consistently make the weld visually defect-free. Turn off the welding machine, shielding gas, and cooling water, and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 17-15

Lap Joint, 3F Position, Using Mild Steel, Stainless Steel, and Aluminum

Repeat Practice 17-14. Gradually increase the plate angle after each weld as you develop your skill. Increase the angle until the weld is being made in the vertical up position, **Figure 17-43**.

Repeat the process using all thicknesses of metal until you can consistently make the weld visually defect-free. Turn off the welding machine, shielding gas, and cooling water, and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 17-16

Tee Joint at a 45° Vertical Angle, Using Mild Steel, Stainless Steel, and Aluminum

Using the same equipment and materials as listed in Practice 17-4, you will make a vertical up fillet weld on a tee joint.

- After tack welding the plates together, start the weld at the bottom and weld in an upward direction. The edge of the side plate, **Figure 17-44**, will heat up more quickly than the back plate. This rapid heating often leads to undercutting along this edge of the weld.
- To control undercutting, keep the arc on the back plate and add the filler metal to the weld pool near the side plate.

Repeat the process using all thicknesses of metal until you can consistently make the weld visually defect-free. Turn off the welding machine, shielding gas, and cooling water, and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 17-17

Tee Joint, 3F Position, Using Mild Steel, Stainless Steel, and Aluminum

Repeat Practice 17-26. Gradually increase the plate angle after each weld as you develop your skill. Increase the angle until the weld is being made in the vertical up position.

Repeat the process using all thicknesses of metal until you can consistently make the weld visually defect-free. Turn off the welding machine, shielding gas, and cooling water, and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 17-18

Stringer Bead at a 45° Reclining Angle, Using Mild Steel, Stainless Steel, and Aluminum

Using the same equipment and materials as listed in Practice 17-4, you will make a weld bead on a plate at a 45° reclining angle, **Figure 17-45**. Add the filler metal along the top leading edge of the weld pool. Surface tension will help hold the weld pool on the top if the bead is not too large. The weld should be uniform in width and reinforcement.

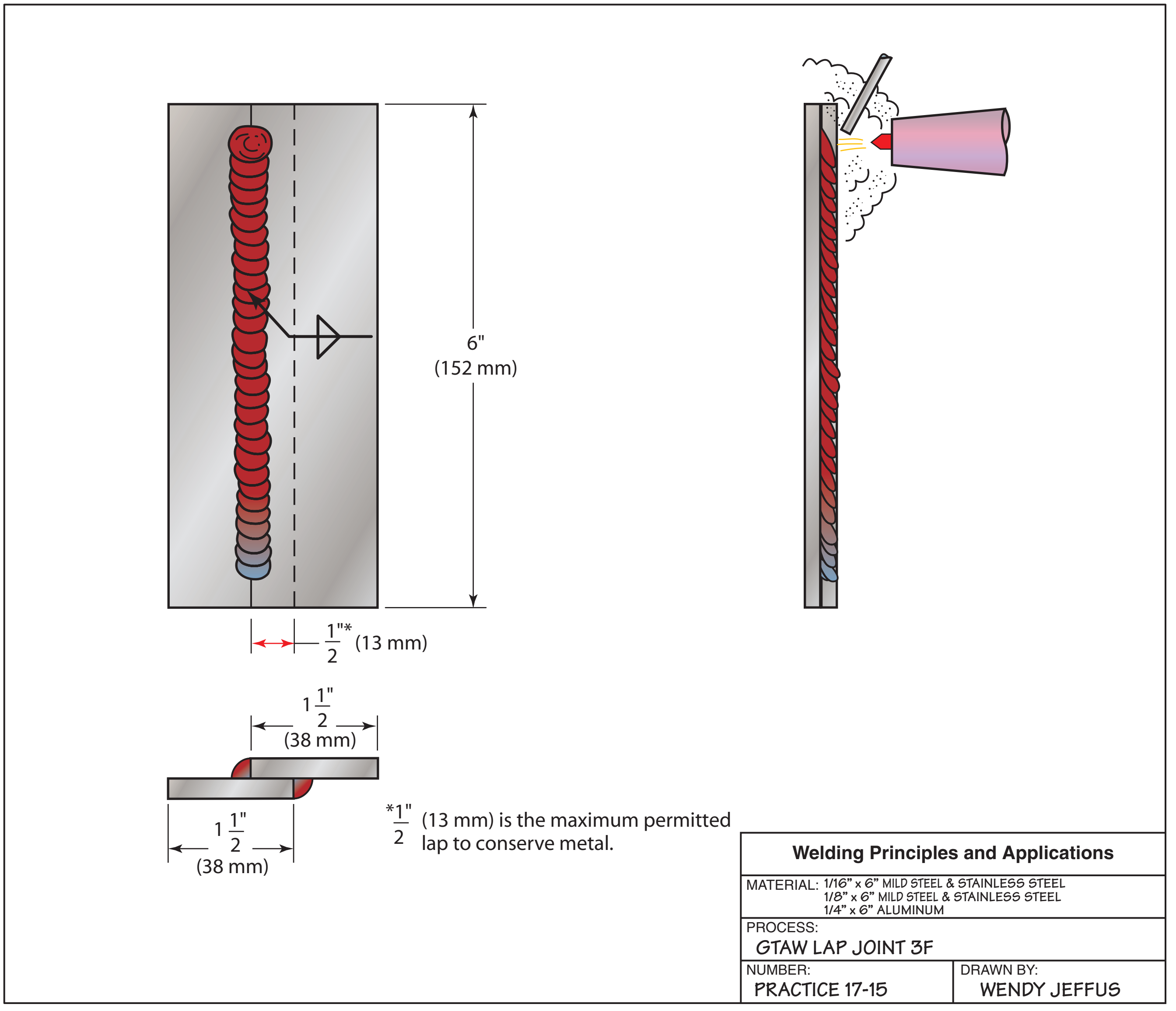


FIGURE 17-43 Vertical up lap joint practice.

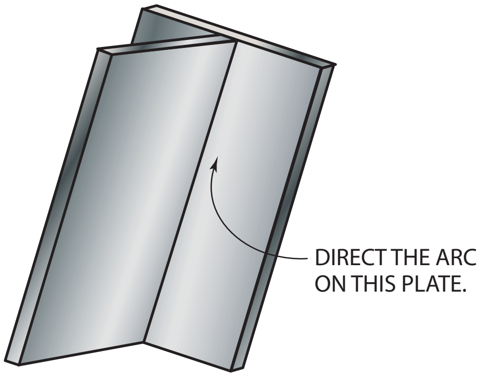


FIGURE 17-44 The edge of the intersecting plate will heat up faster than the base plate if the heat is not directed away from it.

Repeat the process using all thicknesses of metal until you can consistently make the weld visually defect-free. Turn off the welding machine, shielding gas, and cooling water, and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 17-19

Stringer Bead, 2G Position, Using Mild Steel, Stainless Steel, and Aluminum

Repeat Practice 17-18. Gradually increase the plate angle as you develop your skill until the weld is being made in the horizontal position on a vertical plate.

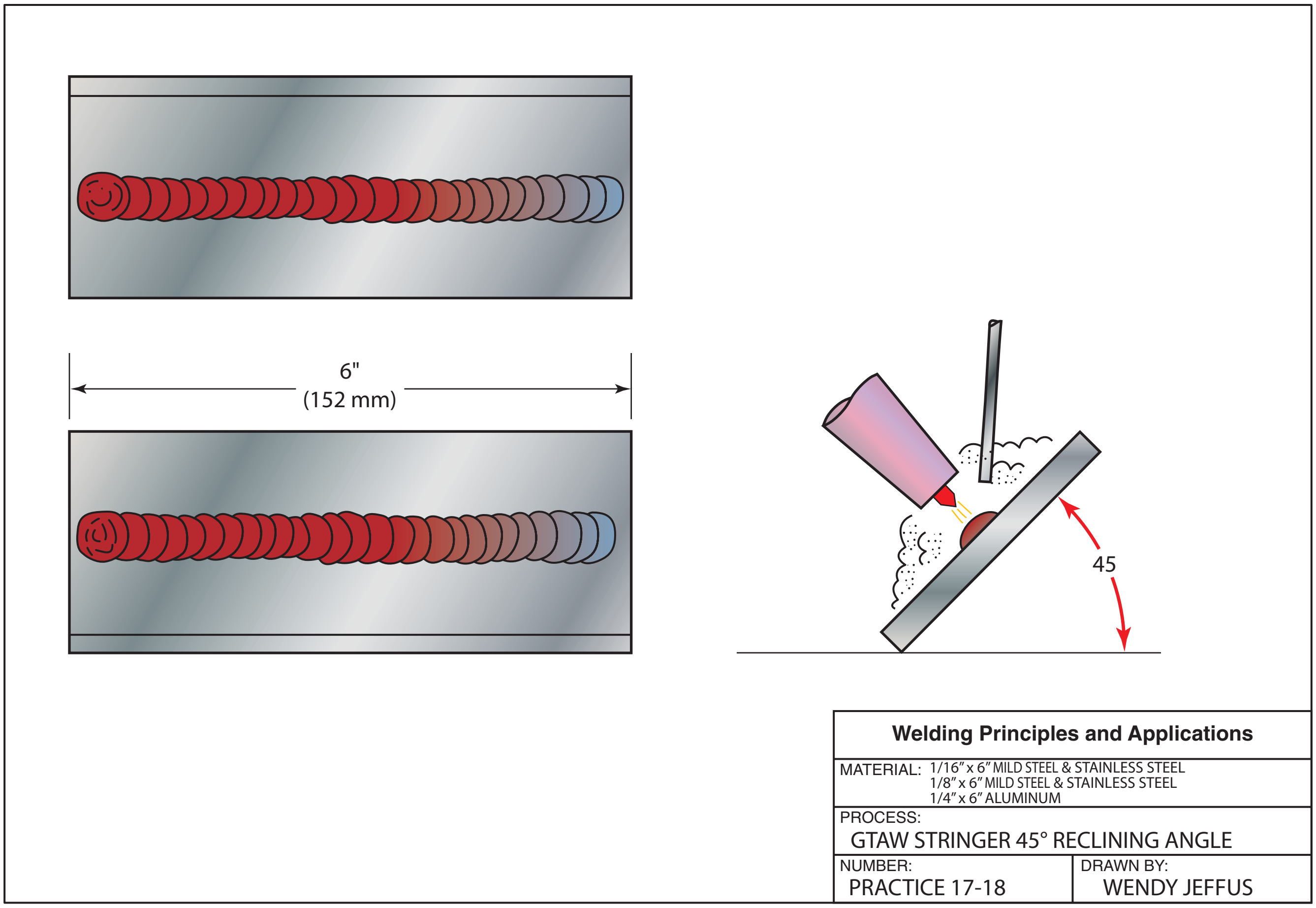


FIGURE 17-45 45° reclining angle stringer bead.

Repeat the process using all thicknesses of metal until you can consistently make the weld visually defect-free. Turn off the welding machine, shielding gas, and cooling water, and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 17-20

Butt Joint, 2G Position, Using Mild Steel, Stainless Steel, and Aluminum

Using the same equipment and materials as listed in Practice 17-4, you will weld a butt joint in the horizontal position, **Figure 17-46**.

The welding techniques are the same as those used in Practice 17-19. Add the filler metal to the top plate, and keep the bead size small so it will be uniform.

Repeat the process using all thicknesses of metal until you can consistently make the weld visually defect-free. Turn off the welding machine, shielding gas, and cooling water, and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 17-21

Lap Joint, 2F Position, Using Mild Steel, Stainless Steel, and Aluminum

Using the same equipment and materials as listed in Practice 17-4, make a horizontal fillet weld on a lap joint.

- After tack welding the plates together, start the weld at one end. The bottom plate will act as a shelf to support the molten weld pool, **Figure 17-47**.
- Add the filler metal along the top edge of the weld pool to help control undercutting.

Repeat the process using all thicknesses of metal until you can consistently make the weld visually defect-free. Turn off the welding machine, shielding gas, and cooling water, and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

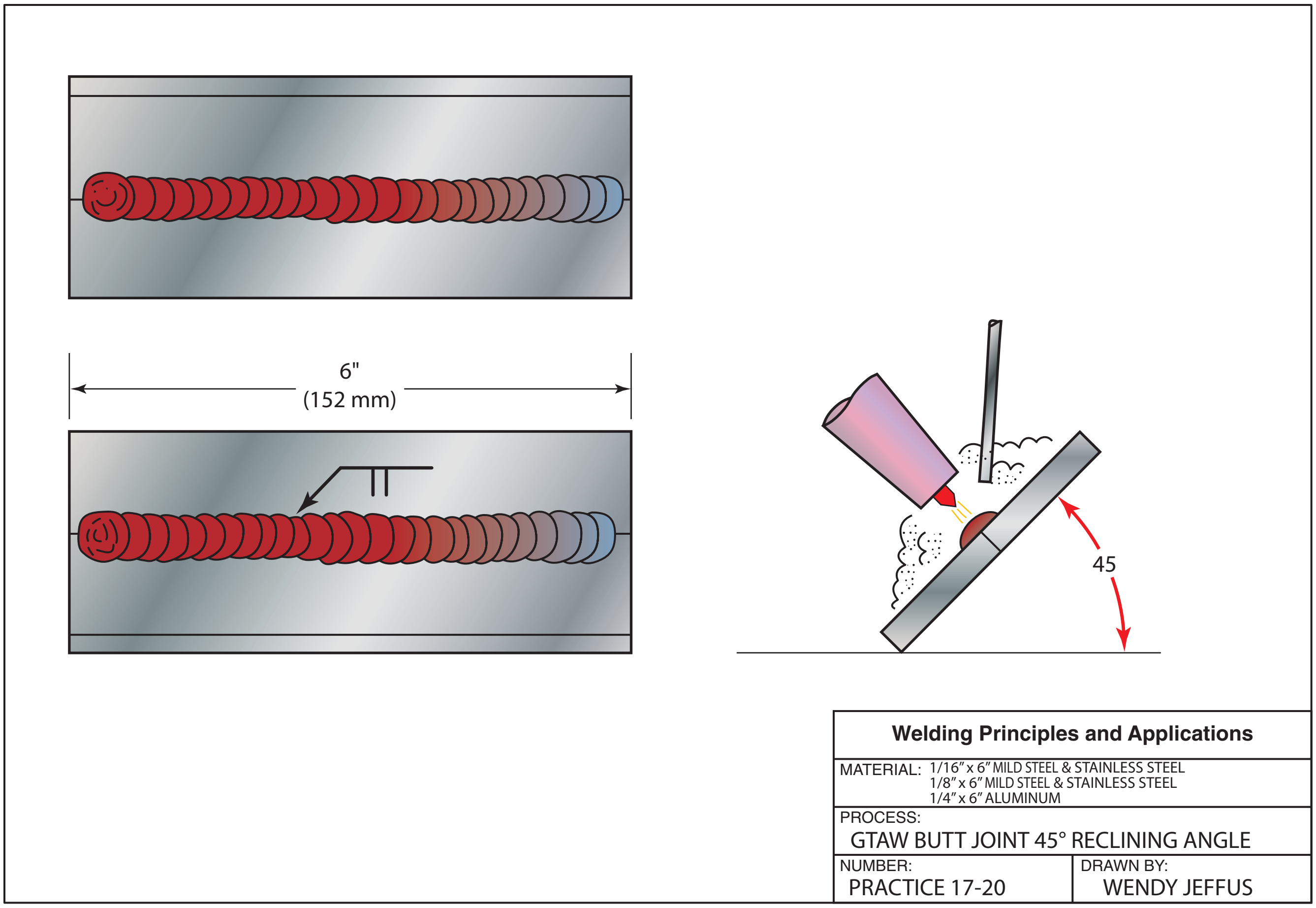


FIGURE 17-46 45° reclining angle butt joint.

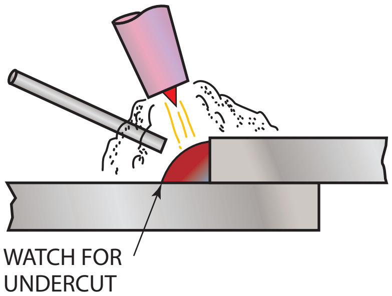


FIGURE 17-47 Lap joint in the horizontal 2F position.

PRACTICE 17-22

Tee Joint, 2F Position, Using Mild Steel, Stainless Steel, and Aluminum

Using the same equipment and materials as listed in Practice 17-4, you will make a horizontal fillet weld on a tee joint.

After tack welding the plates together, start the weld at one end. The bottom plate will act as a shelf to support the molten weld pool, **Figure 17-48**. As with the horizontal lap joint, add the filler metal along the top leading edge of the weld pool. This will help control undercutting.

Repeat the process using all thicknesses of metal until you can consistently make the weld visually defect-free. Turn off the welding machine, shielding gas, and cooling water, and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 17-23

Stringer Bead, 4G Position, Using Mild Steel, Stainless Steel, and Aluminum

Using the same equipment and materials as listed in Practice 17-4, you will make a weld bead on a plate in the overhead position.

The surface tension on the molten metal will hold the welding bead on the plate provided that it is not too large. Add the filler metal along the leading edge of the weld pool, **Figure 17-49**. A narrow weld with little buildup will be easier to control and less likely to undercut along the edge.

Repeat the process using all thicknesses of metal until you can consistently make the weld visually defect-free. Turn off the welding machine, shielding gas, and cooling water, and clean your work area when you are finished welding.

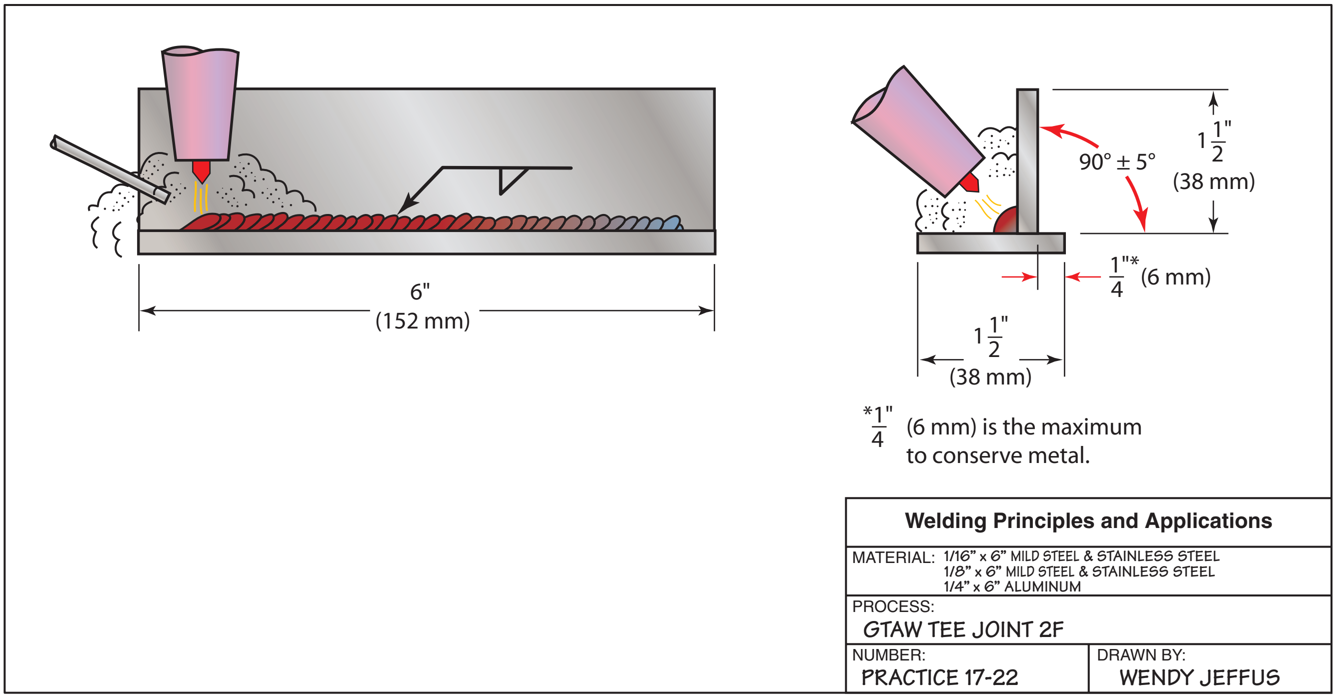


FIGURE 17-48 Tee joint in the horizontal 2F position.

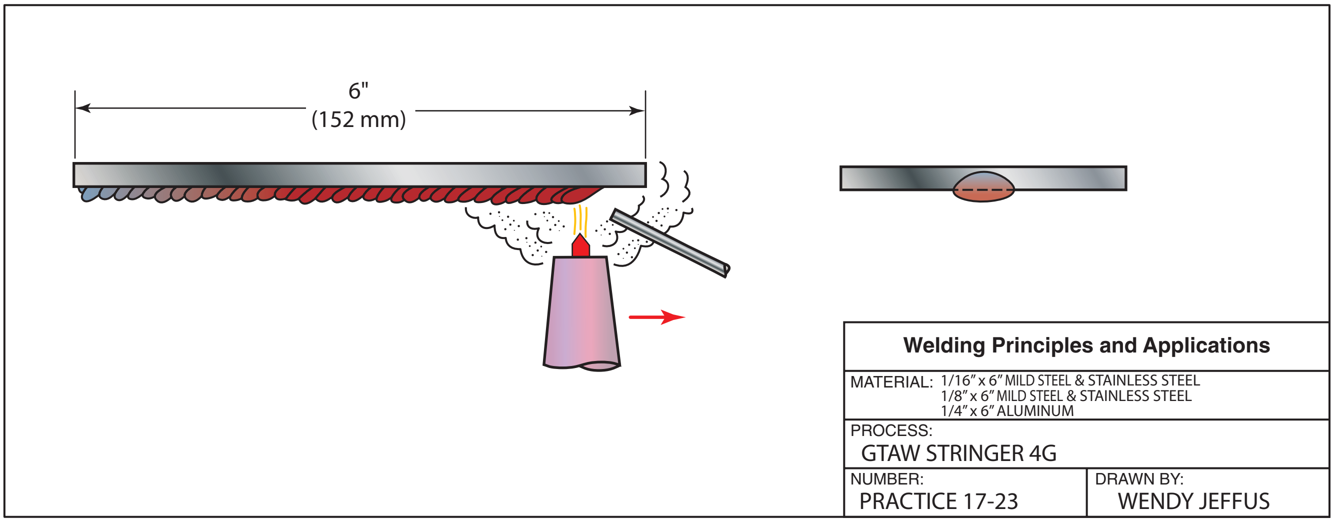


FIGURE 17-49 Overhead stringer bead.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 17-24

Butt Joint, 4G Position, Using Mild Steel, Stainless Steel, and Aluminum

Using the same equipment and materials as listed in Practice 17-4, you will weld a butt joint in the overhead position, **Figure 17-50**.

The same techniques used to make the stringer beads in Practice 17-23 are also used with the butt joint. The size of the bead should be kept small enough so that you can control the weld. The completed weld should be uniform and free from defects.

Repeat the process using all thicknesses of metal until you can consistently make the weld visually defect-free. Turn off the welding machine, shielding gas, and cooling water, and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

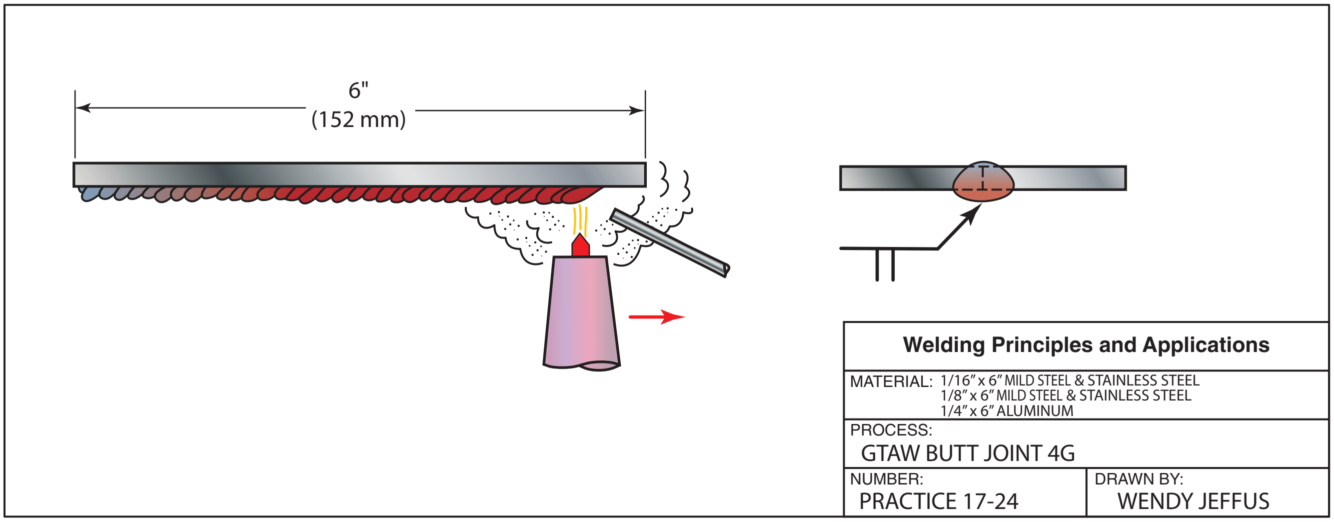


FIGURE 17-50 Overhead butt joint.

PRACTICE 17-25

Lap Joint, 4F Position, Using Mild Steel, Stainless Steel, and Aluminum

Using the same equipment and materials as listed in Practice 17-4, you will make a fillet weld on a lap joint in the overhead position.

The major concentration of heat and filler metal should be on the top plate. Gravity and an occasional sweep of the torch along the bottom plate will pull down the weld pool. Undercutting along the top edge of the weld can be controlled by putting most of the filler metal along the top edge. The completed weld should be uniform and free from defects.

Repeat the process using all thicknesses of metal until you can consistently make the weld visually defect-free. Turn off the welding machine, shielding gas, and cooling water, and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 17-26

Tee Joint, 4F Position, Using Mild Steel, Stainless Steel, and Aluminum

Using the same equipment and materials as listed in Practice 17-4, you will make a fillet weld on a tee joint in the overhead position.

The same techniques used to make the overhead lap weld in Practice 17-25 are used with the tee joint. As with the lap joint, most of the heat and filler metal should be concentrated on the top plate. A "J" weave pattern will help pull down any needed metal to the side plate. The completed weld should be uniform and free from defects.

Repeat the process using all thicknesses of metal until you can consistently make the weld visually defect-free. Turn off the welding machine, shielding gas, and cooling water, and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

Summary

One of the most difficult aspects of learning to produce gas tungsten arc welds is positioning yourself so that you can control the electrode filler metal and see the joint at the same time. Beginning welders assume they must see the tungsten tip as they make the weld. Experienced welders, however, realize that they need to see only the leading edge of the molten weld pool to know how the weld is being produced. A good view of the leading edge will tell you how the base metal is being melted, or depth of penetration. You can even tell from this small portion whether the filler metal is being added at an appropriate rate. As you learn how to control the weld and develop your skills, it is a good idea to gradually reduce your need for seeing 100% of the molten weld pool. Increasing this part of your skill will be a significant advantage in the field because, unlike welding in the classroom, which is typically done on a table of comfortable height, welding in the field sometimes requires that you work in unusual positions.

Review

1. What effect does torch angle have on the shielding gas protective zone?
2. Why must the end of the filler rod be kept in the shielding gas protective zone?
3. What can cause tungsten contamination?
4. What determines the correct current setting for a GTA weld?
5. What is the lowest acceptable amperage setting for GTA welding?
6. List the factors that affect the gas flow setting for GTA welding.
7. When should the minimum gas flow rates be increased?
8. What is the minimum gas flow rate for a nozzle size?
9. What is the maximum gas flow rate for a nozzle size?
10. Which incorrect welding parameters does stainless steel show clearly?
11. Using Table 17-4, determine the approximate temperature of metal that has formed a dark blue color.
12. Using Table 17-3, Table 17-5, and Table 17-6, list the filler metals for the following metals.
    a. 1020 low carbon steel
    b. 309 stainless steel
13. Why is it possible to control a large aluminum weld bead?
14. What may happen to the end of the aluminum welding rod if it is held too close to the arc?
15. What should be done if someone comes in contact with a cleaning chemical?
16. Using Table 17-7, determine the suggested setting for GTA welding of mild steel using a 3/32-in. (2.4-mm) tungsten.
17. What can be done to limit oxide formation on stainless steel?
18. How should the filler metal be added to the molten weld pool?
19. How can the rod be freed if it sticks to the plate?
20. How is an outside corner joint assembled?
21. What must be done with the weld craters when back stepping a weld? Why?
22. What can prevent both sides of a stainless steel tee joint from being welded?
23. How is the filler metal added for a 3F weld?
24. What can cause undercutting on a 3F tee joint?
25. What helps hold the weld in place on a 2F lap joint?
26. What helps hold the weld in place on a 4G weld?

Chapter 18

Gas Tungsten Arc Welding of Pipe

OBJECTIVES

After completing this chapter, the student should be able to

- describe how a pipe joint is prepared for welding.
- list the four most common root defects and the causes of each defect.
- discuss when and why a backing gas is used.
- explain the uses of a hot pass.
- sketch a single V-groove and indicate the location and sequence of welds for each position.
- make a single V-groove butt welded joint on a pipe in any position.

KEY TERMS

backing gas	*grapes*	*root penetration*
concavity	*incomplete fusion*	*root reinforcement*
consumable inserts	*root*	*stress point*

INTRODUCTION

Gas tungsten arc welding of pipe is used when the welded joint must have a high degree of integrity. A weld with integrity is one that is strong and free from defects that may cause the premature failure of the welded joint. Many industries, such as oil, gas, nuclear, chemical, and several others, require this kind of joint to be made, **Figure 18-1**. Failures in these types of pipe joints can be disastrous in addition to being extremely expensive to repair.

GTA welding gives industry the type of joint it needs. Welders who are skilled in the GTA welding process have the ability to make consistently high-quality welds with a low rejection rate.

GTA pipe welders are among the highest paid workers in the welding industry. The positions available are among the safest and most prestigious and have excellent working conditions. Preparing for such a job requires the development of high levels of skill and technical knowledge through much practice and study.

FIGURE 18-1 Automatic GTA outside pipe welding machine.

PRACTICES

The practices in this chapter are all performed on mild steel pipe. Mild steel is the most readily available material on which to learn. The skill and techniques learned in these practices can be easily transferred to any other piping material. In most cases, the only change is in the composition of the filler material and possibly the current.

JOINT PREPARATION

The ends of pipe must be grooved before welding. This pipe end preparation is to ensure a sound weld. The type of groove used in preparing the ends of a pipe for welding will vary depending on the pipe material, thickness, and application. The V-groove is the most commonly used pipe end preparation. Some other end preparations that can be used are the U-groove, J-groove, and bevel-groove, **Figure 18-2**. Both the single bevel-groove and single V-groove can be easily flame cut or ground. This factor makes them the most frequently used grooves during training.

V-Groove

The end of the pipe is prepared with a 37 1/2° bevel, leaving a root face of 1/16 in. (2 mm) to 1/8 in. (3 mm), **Figure 18-3**. When both pipes are prepared in this manner, they form a 75° single V-groove. The groove angle allows good visibility of the weld with a minimum amount of filler metal required to fill the groove. The grinding or machining of the sharp edge left on the pipe after beveling produces the root face. The root face is the small flat surface at the root of the groove. Failure to remove the root edge may result in the weld burning back the material, leaving too large of a key hole to be filled by the weld. This may result in a concave root surface, sometimes referred to as *suck back*, **Figure 18-4**.

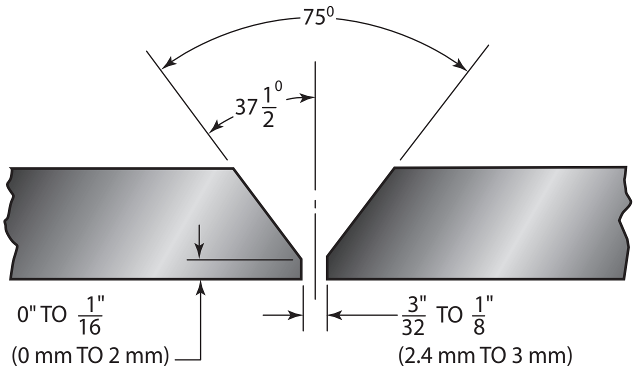


FIGURE 18-3 Typical V-groove preparation dimensions.

Joint Cleaning

Before the joint is assembled, the welding surfaces must be cleaned and smoothed so that they are uniform and free of contaminants. To remove any possible sources of

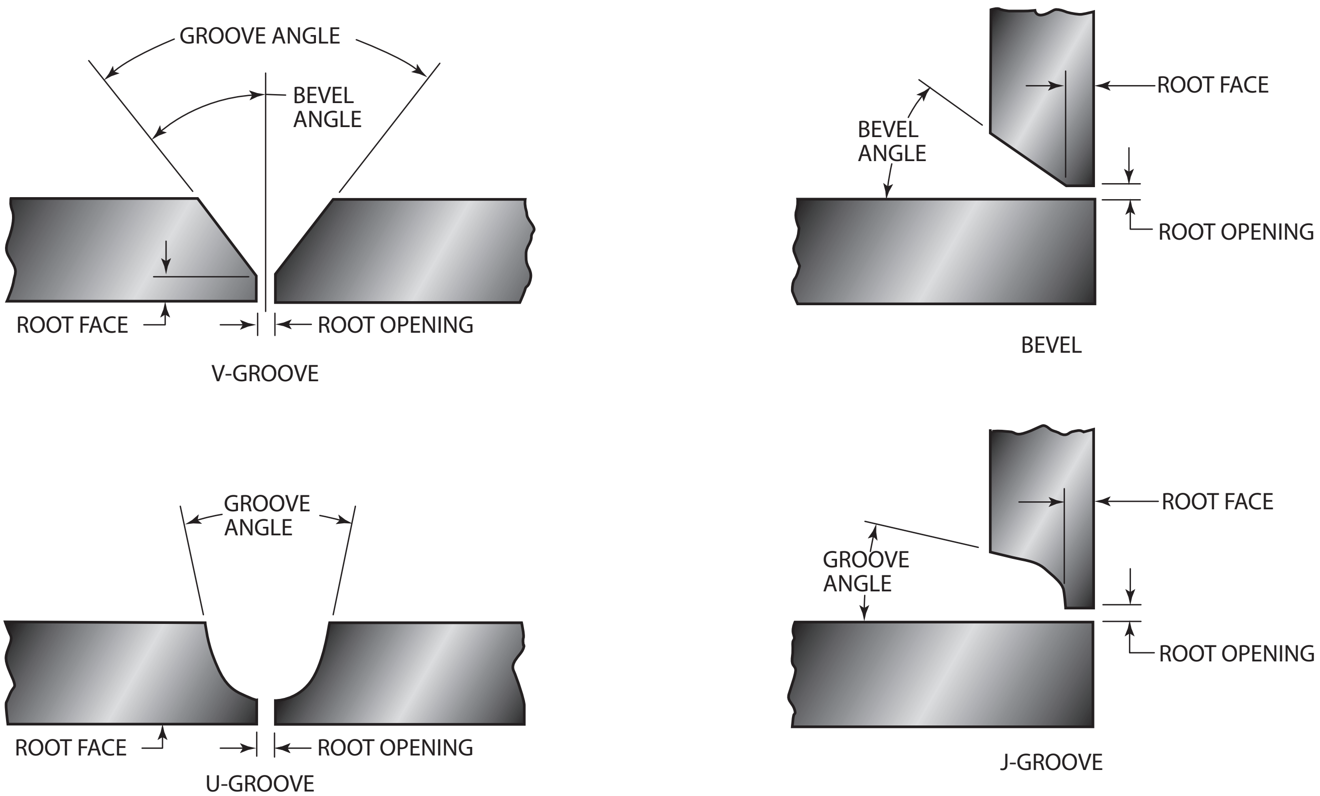


FIGURE 18-2 Grooves used for pipe-to-pipe and pipe-to-flange welds.

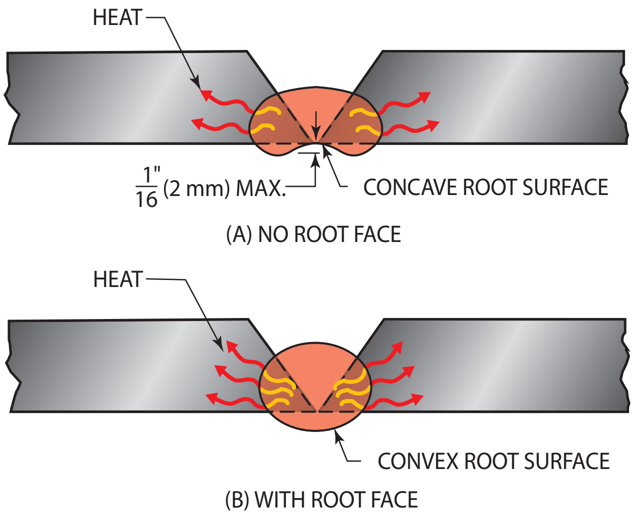


FIGURE 18-4 (A) This joint cannot conduct enough heat away from the root pass to provide support for the molten root pass. Note the concave surface of the root face caused by suck-back. (B) The larger mass of metal helps to cool the puddle quickly and provides for sufficient surface tension, which also helps control the root surface.

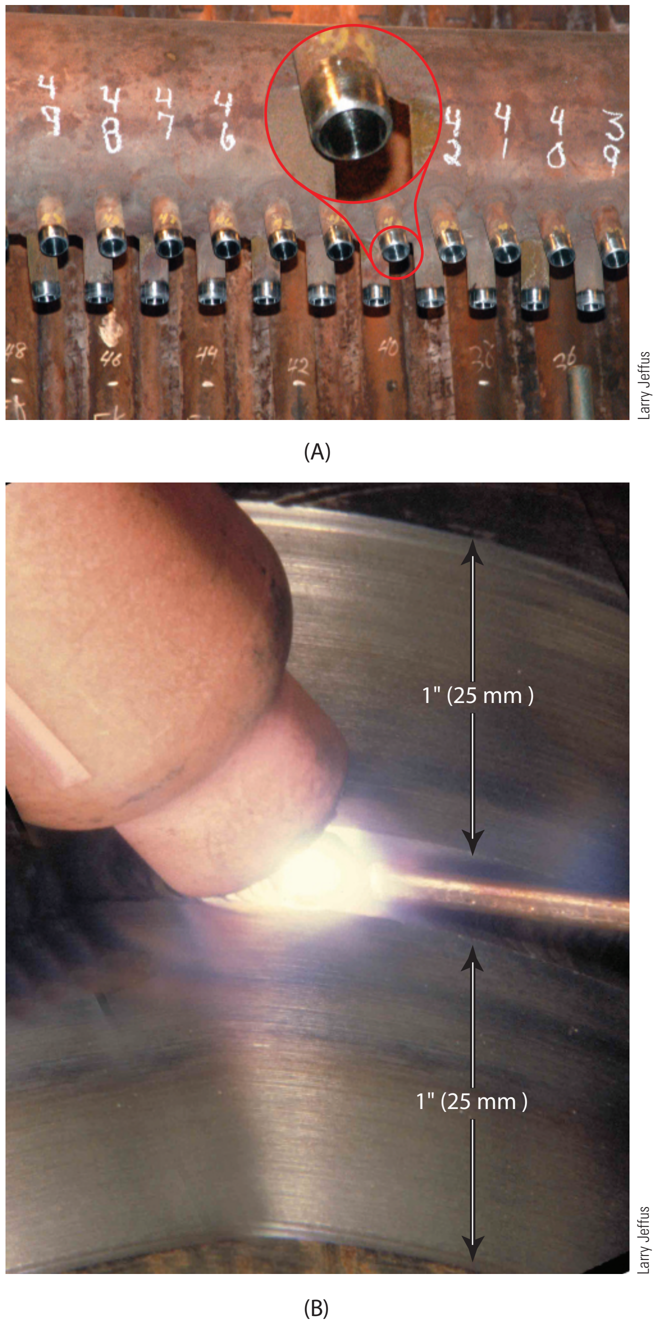


FIGURE 18-5 (A) The pipe is machine cleaned on the inside and outside surfaces. (B) The groove must be cleaned, both outside and inside the pipe joint.

contamination to the weld, clean a 1-in. (25-mm)-wide or wider band both inside and outside of the pipe, **Figure 18-5**. The band can be cleaned by grinding, brushing, or filing. The prepared edges must be clean and free from tears, cracks, slivers, or any other defects. Once the pipe surface has been cleaned, it is important that it not be touched with your hand because oil on your hand can contaminate the weld, **Figure 18-6**.

NOTE

When making welds on critical piping systems or when welding piping systems made with reactive metals such as titanium, you must clean both the filler metal and weld surface. Using a lint-free cloth and a solvent such as isopropyl alcohol, acetone, or methyl ethyl ketene (MEK), clean the filler metal and joint surface just before welding begins. And once the material is cleaned, always wear oil-free chemically resistant gloves, such as nitrile gloves, when handling the cleaned material.

The pipe should be tack welded together with a root opening of 3/32 in. (2.4 mm) to 1/8 in. (3 mm). Four or more tack welds evenly spaced around the pipe should be made. The tack welds must be strong enough to withstand the forces created by the root weld's expansion and contraction as it is being made in the groove. For the practices in this book they should be approximately 1-in. (25-mm), but in the field they may be 2 in. long or longer. The ends of the tack welds should be ground to a featheredge with a narrow grinding disk. This allows the weld to be started and stopped on the tack weld and to have 100% penetration at its beginning and ending, **Figure 18-7**.

ROOT

The **root** of a weld is the deepest point into the joint where fusion between the base metal and filler metal occurs. The **root penetration** is the distance measured between the original surface of the joint and the deepest point of fusion. The **root reinforcement** is the amount of metal deposited on the back side of a welded joint, **Figure 18-8**.

The depth to which a weld must penetrate in a pipe joint, or the amount of root reinforcement, is given in the

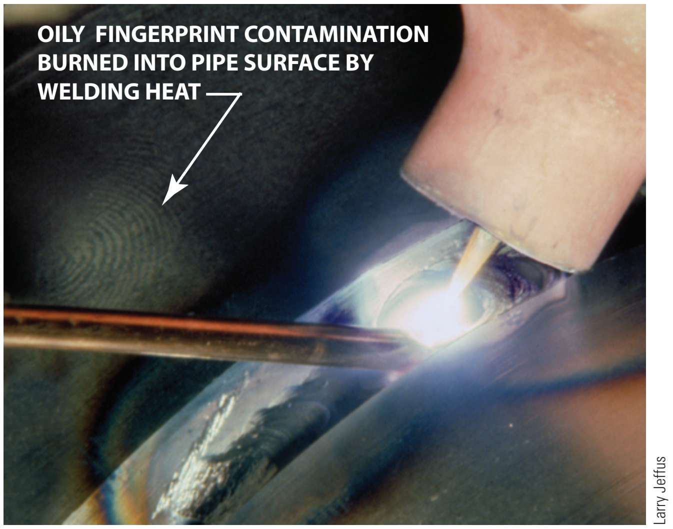


FIGURE 18-6 Oily fingerprint contamination.

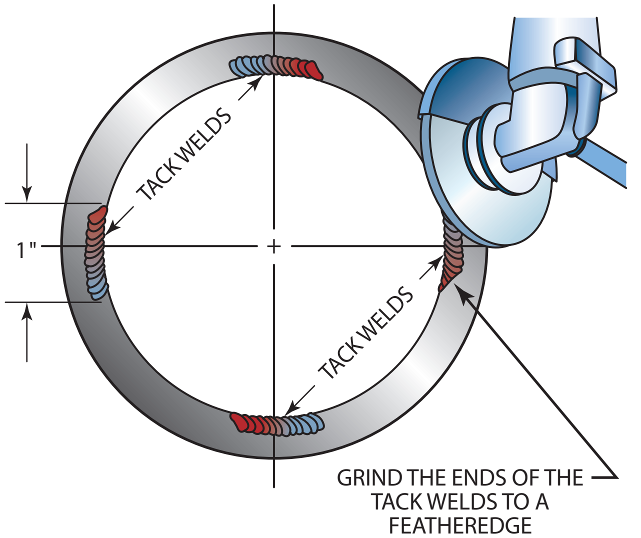


FIGURE 18-7 Location of tack welds on small-diameter pipe.

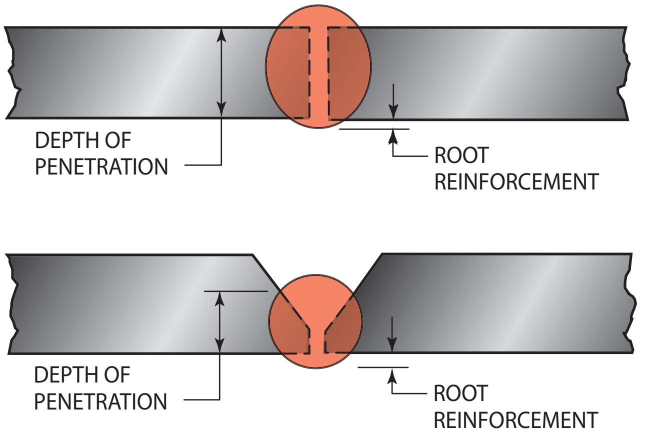


FIGURE 18-8 Root penetration and reinforcement.

code or standards being used. Most codes or standards for GTA pipe welding require 100% root penetration and no more than 1/16 in. (2 mm) of root reinforcement. Uniformity and the lack of defects in a weld are also important. The four most common root defects are **incomplete fusion**, concave root surface (suck back), excessive root reinforcement, and root contamination.

Incomplete Fusion

Sometimes a weld does not completely penetrate the joint, or there may be a lack of fusion on one or both sides of the root. These conditions are caused by not enough heat penetrating the back side of the work, **Figure 18-9.** The problem with incomplete fusion is that it can form a **stress point.** Stress points can result in the premature cracking or failure of the weld at a load well under its expected strength.

Incomplete fusion can be observed if the weld is subjected to a root-bend test. A root bend subjects a welded joint to a bending force so that the root of the weld is in tension, **Figure 18-10**. One test that can be used is a standard test procedure (guided bend or free bend). Another

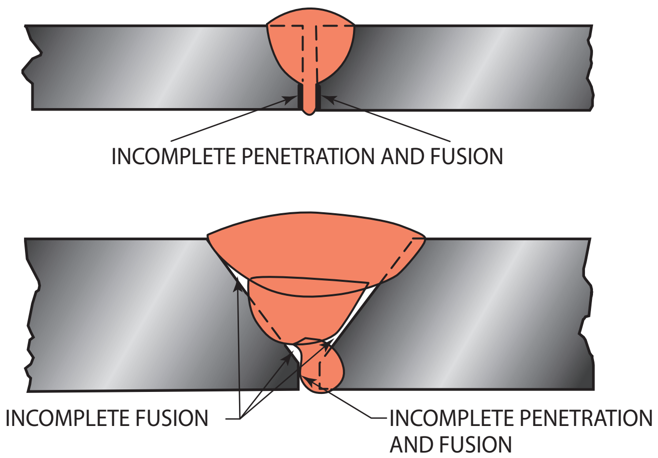


FIGURE 18-9 Lack of fusion.

FIGURE 18-10 Guided bend test specimen.

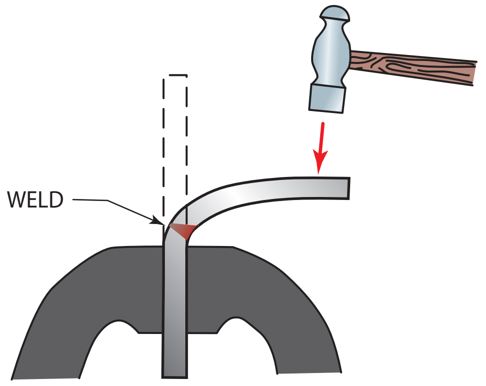


FIGURE 18-11 Bend test using a hammer and vise.

test that can be used is to simply secure the welded joint in a vise and use a hammer to bend the metal, **Figure 18-11**.

Concave Root Surface

A concave root surface (suck back) occurs when the back side of the root weld is concave in shape, Figure 18-4A. Common causes for this condition are when insufficient filler metal is added to the joint, or excessive heat is used in the overhead position. The **concavity** of the root surface results in reduced thickness (actual throat) of the weld, which in turn causes a lower joint strength.

Concave root surface can be visually inspected (VI) readily without destructive testing. The amount of concavity can be given

- as a percentage of the total weld length,
- as the average number and largest size of spots per inch (mm) of weld, or
- as a percentage of the effective throat. Normally, 1/16 in. (2 mm) is the maximum allowable root concavity.

Excessive Root Reinforcement

Excessive root reinforcement or burnthrough is the excessive buildup of metal on the back side of a weld. Uneven buildup and burnthrough are sometimes referred to as **grapes**. This condition results from excessive heat, temperature, and filler metal during welding. Excessive root reinforcement can cause reduced material flow, result in clogged pipes, or form stress points that will result in premature weld failure.

The root of the weld should have some reinforcement (buildup), but this should not exceed 1/16 in. (1.5 mm). Visual inspection (VI) can be used to verify this condition, **Figure 18-12**. The amount of excessive reinforcement is given

- as a percentage of the total weld length,
- as the average number and largest size of spots per inch (mm) of weld, or
- as the maximum distance from the metal surface to the longest spot of excessive reinforcement.

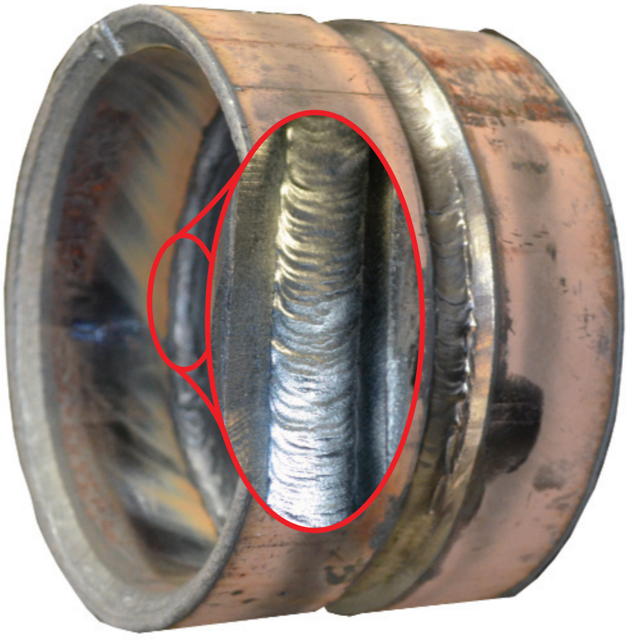


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FIGURE 18-12 Visually examine the root face.

Root Contamination

The back side of the molten weld pool can be contaminated, causing porosity, embrittlement, oxide inclusions, and/or oxide layers. Contamination is caused by overheating, poor cleaning procedures, or improper protection from the surrounding atmosphere, **Figure 18-13**. Root contamination can lead to faster corrosion, oxide flaking, weld brittleness, leaks, stress points, or all of these.

Root surface contamination can be visually inspected. Heavy flakes and large deposits of oxides are signs of root surface contamination. Ideally, the color of the root should be close to that of the base metal. Internal porosity, oxides, or embrittlement can be detected readily by a root-bend test. The weld deposit should be as ductile (easily bent) as the surrounding base metal.

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FIGURE 18-13 Root contamination.

BACKING GAS

Root contamination caused by the surrounding atmosphere is not a major problem when welding on mild steel pipe. Some type of protection, however, is needed when welding on alloy steel, stainless steel, aluminum, copper, and most other types of pipe. The easiest method of protecting the root from atmospheric contamination is to use a **backing gas**.

The type of gas used for backing will depend on the type of pipe being welded. Nitrogen and CO_2 are often acceptable, depending on the code or intended use of the pipe system. Argon, although expensive, can be used to back any type of pipe if a welder is unsure about a less expensive substitution.

Purging

There are several methods in common use for containing the backing gas in the pipe. On small diameters or short sections of pipe, the ends of the pipe are capped, **Figure 18-14**. The gas is allowed to purge the complete pipe section of air. This method requires too much purging time and gas to be practical on large diameter pipe. For larger diameters, the pipe is plugged on both sides of the joint to be welded so that a smaller area can be purged. If the piping system is complex, consisting of valves and numerous turns, then water-soluble plugs or soft plastic gas bags are suggested. They can be blown out with air or water when the system is completed.

When a backing gas is used, the gas must have enough time to purge the pipe completely of air. When welding on large diameter pipes or long pipe sections, it is necessary to estimate the length of time required to purge the air. First, estimate the interior volume of the pipe. Second, convert the flow rate into cubic inches per minute (cm^3/min). Third, to get the time required, divide the estimated volume by the flow rate. Finally, round off any fractions of minutes to the next highest minute.

Standard Units

1st Volume (in.^{3}) = length (in.) $\times$ π $\times$ radius^2 (in.)
2nd Flow rate (in.^{3}/min) = cfh $\times$ 29*
3rd Flow time (mm) = volume $\div$ flow rate

SI (Metric Units)

1st Volume (cubic cm) = length (in cm) $\times$ π $\times$ radius^2 (in cm)
2nd Flow rate (cm/min) = L/mm $\times$ 1000
3rd Flow time (min) = volume $\div$ flow rate

Standard Unit Example

How long would it take to purge the air out of a 10-ft- (305-cm) long section of 4-in. (10-cm) diameter pipe if the flow rate is 20 cfh (9.4 L/min)?

Solution

$$\begin{aligned}
\text{Volume} &= 120 \times 3.14 \times 2^2 \\
\text{Volume} &= 1507 \text{ in.}^3 \\
\text{Flow rate} &= 20 \times 29 \\
\text{Flow rate} &= 580 \text{ in.}^3\text{/min} \\
\text{Flow time} &= 1507 \div 580 \\
\text{Flow time} &= 2.59 \text{ min (approximately 3 min)}
\end{aligned}$$

SI (Metric Unit) Example

How long would it take to purge the air out of a 3-m- (10-ft) long section of 10-cm (4-in.) diameter pipe if the flow rate is 9 L/min (20 cfh)?

$$\begin{aligned}
\text{Volume} &= 300 \times 3.14 \times 5^2 \\
\text{Volume} &= 23{,}550 \text{ cm}^3 \\
\text{Flow rate} &= 9 \times 1000 \\
\text{Flow rate} &= 9000 \text{ cm}^3\text{/min} \\
\text{Flow time} &= 23{,}550 \div 9000 \\
\text{Flow time} &= 2.61 \text{ min (approximately 3 min)} \\
\pi &= 3.14 \\
\text{Radius} &= 1/2 \text{ diameter*} \\
\text{Length in in.} &= \text{length in ft} \times 12 \\
\text{Length in cm} &= \text{length in m} \times 100
\end{aligned}$$

*29 (28.8) cubic inches per minute flow rate equals a flow rate of 1 cubic foot per hour.

Taping over the joint prevents the gas from being blown out through the joint. This will allow a slower flow rate to be used on the purging gas once the pipe has been purged. The tape is removed just ahead of the weld, **Figure 18-15**.

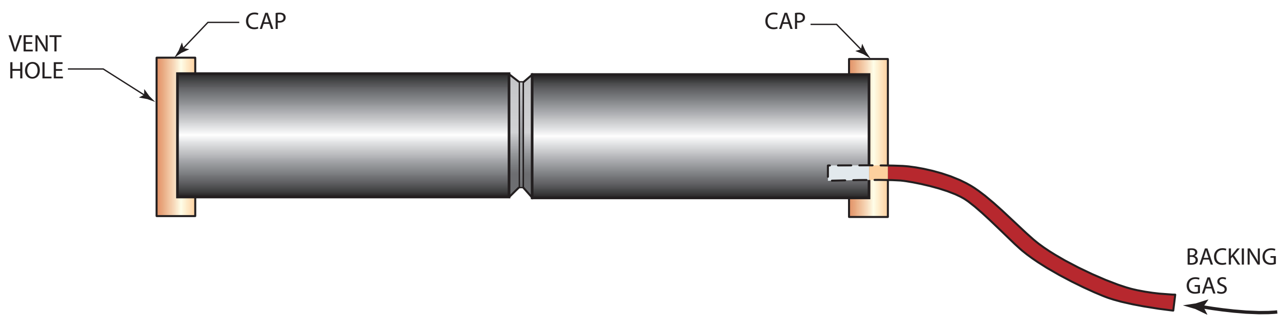

FIGURE 18-14 Backing gas can be fed into a pipe for welding by capping the ends externally.

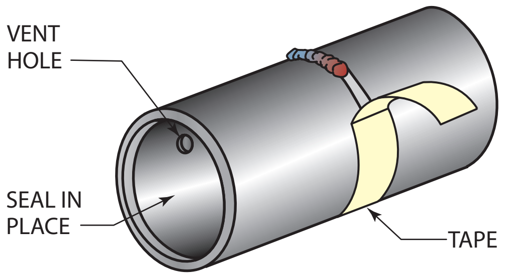

FIGURE 18-15 Using a special tape to cover the unwelded part of a pipe joint will reduce the need for high flow rates for the backing gas.

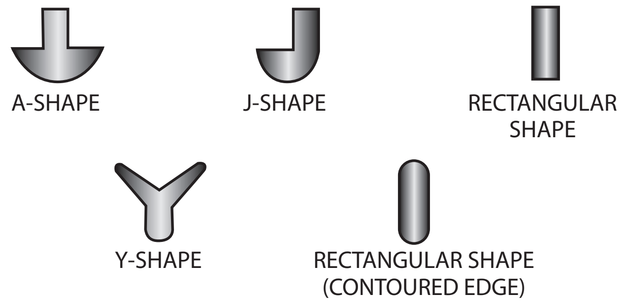

FIGURE 18-17 Consumable insert standard shapes.

FILLER METAL

The addition of filler metal to the joint can be done by dipping or by preplacement. Dipping can be made easier if the rod is bent to the radius of the pipe, **Figure 18-16**. This will allow the welder to keep the rod angle close to the pipe to minimize contamination. This also makes it possible for welders to reach around the pipe and brace themselves better. The groove can also be used to guide the filler rod, reducing tungsten contamination.

Preplacing the filler rod allows the root pass and some filler passes to be made without rod manipulation. The filler rod, usually 1/8 in. (3 mm) in diameter, is bent in a radius slightly smaller than the pipe being welded. Tension from the wire will hold it in place during the weld. If it does not stay in place, then a small tack weld can be made at one end. Both hands can be used to control the torch, making the weld easier and more accurate. This technique is accepted in most codes or standards for welding.

Consumable Inserts

Consumable inserts are preplaced filler metal, which is used for the root pass when consistent, high-quality welds are required. These inserts help to reduce the number of repairs or rejections when welding under conditions that are less than ideal, such as in a limited space. Although most inserts are used on pipe, they are available as strips for flat plate.

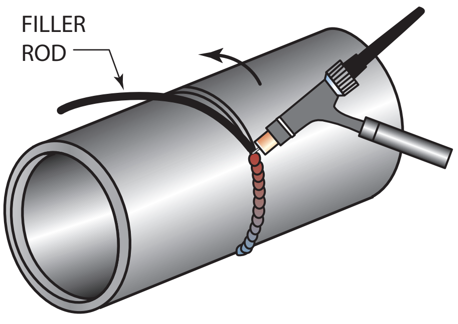

FIGURE 18-16 Filler rod curved to surface of pipe for ease in welding.

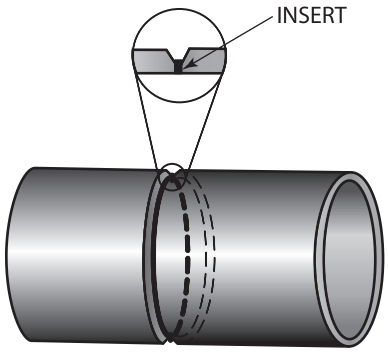

FIGURE 18-18 Specialized backing rings.

Inserts are classified by their cross-sectional shape, as shown in **Figure 18-17**, and listed as follows:

- Class 1, A-shape
- Class 2, J-shape
- Class 3, rectangular shape
- Class 4, Y-shape
- Class 5, rectangular shape (contoured edges)

These are the most frequently used designs, **Figure 18-18**. Other shapes can be obtained from manufacturers upon request.

When ordering **consumable inserts**, the welder must specify the classification, size, style, and pipe schedule. Other information is available in the AWS Publication A5.30, *Specification for Consumable Inserts.*

PRACTICE 18-1

Tack Welding Pipe

Using a properly set-up and adjusted GTA welding machine, proper safety protection, two or more pieces of 3-in. (76-mm) to 10-in. (254-mm) diameter schedule 40 mild steel pipe prepared with single V-grooved joints, and a few filler rods with 1/16-in. (2-mm), 3/32-in. (2.4-mm), and 1/8-in. (3-mm) diameters, you will tack weld a butt pipe joint.

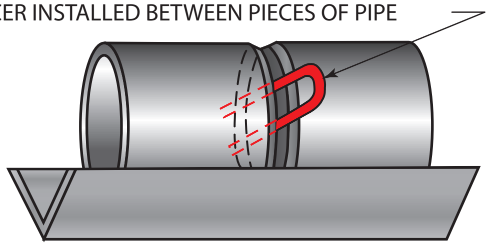

FIGURE 18-19 Use a spacer like a piece of filler metal to set the root gap.

Bend the rods with the 1/16-in. (2-mm) and 3/32-in. (2.4-mm) diameters into a U-shape. These rods will be used to set the desired root opening, **Figure 18-19**. Lay the pipe in an angle iron cradle. Slide the ends together so that the desired diameter wire is held between the ends. Hold the torch cup against the beveled sides of the groove. The torch should be nearly parallel with the pipe. Bring the filler rod end in close and rest it on the joint just ahead of the torch, **Figure 18-20**.

Lower your helmet and switch on the welding current by using the foot or hand control. Slowly straighten the torch so that the tungsten is brought closer to the groove. This pivoting of the torch around the nozzle will keep the torch aligned with the joint and help prevent arc starts outside of the joint. When the tungsten is close enough, the high frequency will be established. Increase the current by depressing the foot or hand control until a molten weld pool is established on both root faces.

Hold the filler rod tip in the molten weld pool as the torch is pivoted from side to side, **Figure 18-21**. Slowly move ahead and repeat this step until you have made a tack weld approximately 1 in. (25 mm) long. At the end of the tack weld, slowly reduce the current and fill the weld crater. If the tack weld crater is properly filled and it does not crack, then grinding may not be required, **Figure 18-22**.

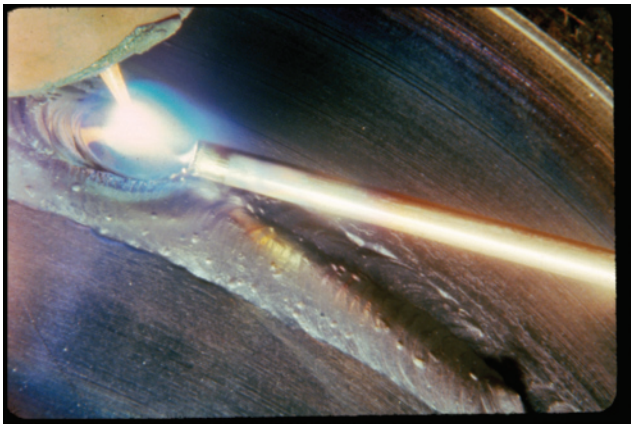
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FIGURE 18-21 Adding filler metal to weld pool.

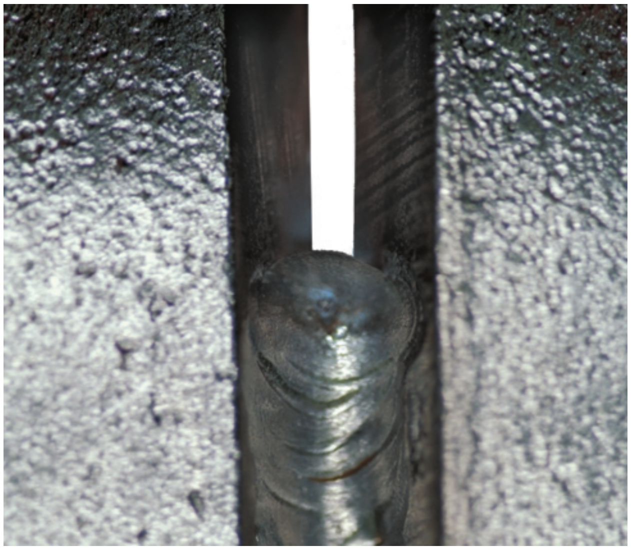
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FIGURE 18-22 Good stopping point for a weld that will be restarted.

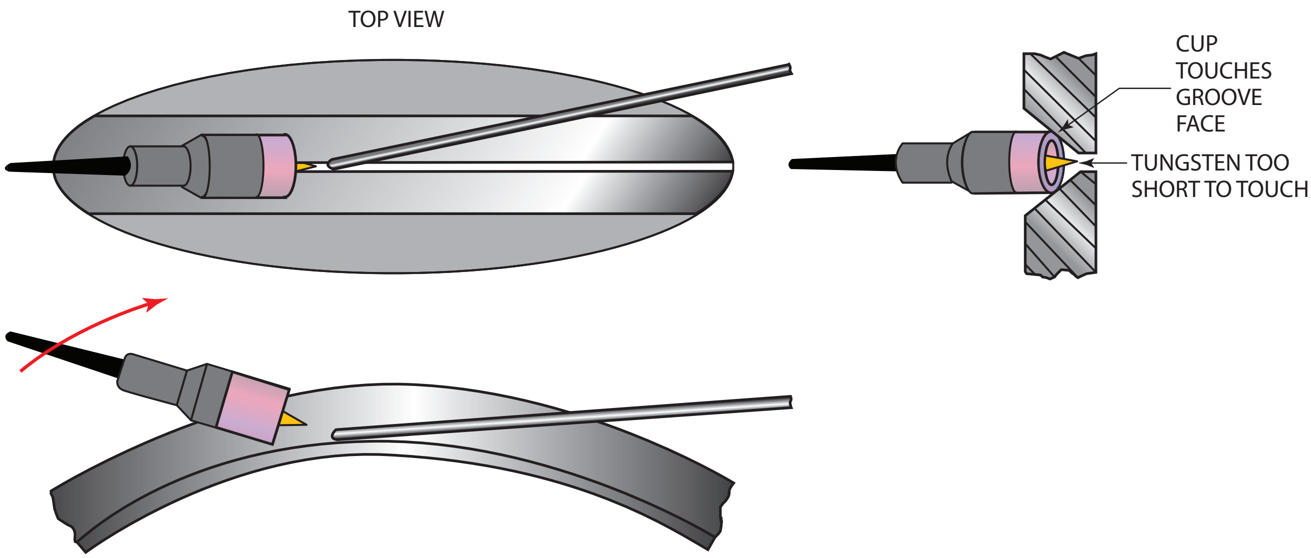

FIGURE 18-20 Supporting the torch and filler rod in the groove will help when making the tack welds.

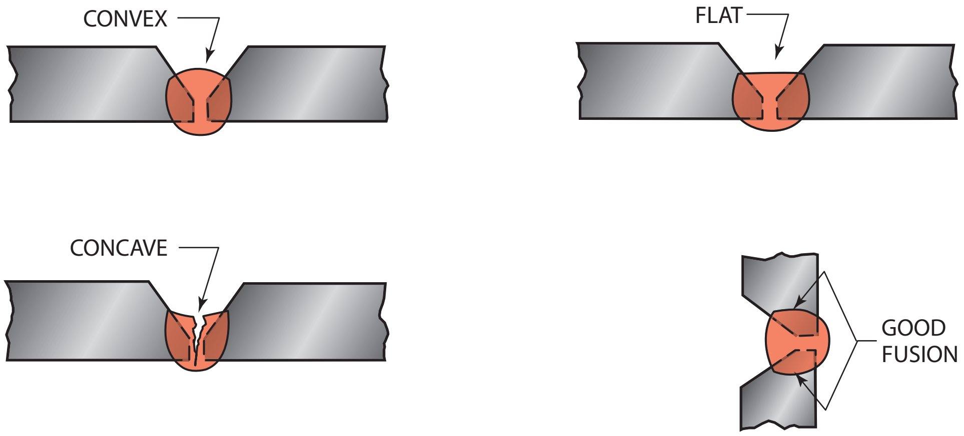

FIGURE 18-23 Concave tack welds may crack because they cannot withstand the stresses during cooling.

Roll the pipe 180° to the opposite side. Check the root opening and adjust the opening if needed. Make a tack weld 1 in. (25 mm) long. Roll the pipe 90° to a spot halfway between the first two tacks. Check and adjust the root opening if needed. Make a tack weld. Roll the pipe 180° to the opposite side and make a tack weld halfway between the first two tack welds.

The completed joint should have four tack welds evenly spaced around the pipe (at 90° intervals). The root surfaces of the welds should be flat or slightly convex. The tacks should have good fusion into the base metal with no cold lap at the start, **Figure 18-23**.

Continue making tack welds until this procedure is mastered. Turn off the welding machine, shielding gas, and cooling water and clean up your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

CUP WALKING

Although the cup walking technique can be used on plate, it is most often used by pipe welders. Plate welders do not often use cup walking because it can be slower than traditional welding techniques; however, many pipe welders like to use it for several reasons:

- Reduced welder fatigue—Because the welding torch nozzle and filler metal are both resting on the pipe, welders can relax because they are less likely to touch the electrode to the weld or filler metal.
- Better welding torch control—The small uniform stepping movement of the torch nozzle along the weld results in a weld appearance that is more uniform and defect-free than manual welding.
- Longer welds—Often welders can weld from the bottom to the top of the pipe without having to stop and reposition. Stops and starts are a primary cause of GTA weld defects.
- Higher weld quality—Less tungsten contamination, more uniform welds, and fewer stops and starts result in high-quality pipe welds.

Cup Walking Setup

The tungsten length should be set so it extends out of the nozzle no more than the diameter of the nozzle opening, **Figure 18-24**. If the tungsten sticks out too much, then it is more likely to become contaminated by touching the weld or filler metal. When making the root pass and the first one or two filler passes, the nozzle diameter should be large enough to touch both sides of the groove edges, **Figure 18-25**. A larger nozzle size may be needed for the last filler pass and cover pass.

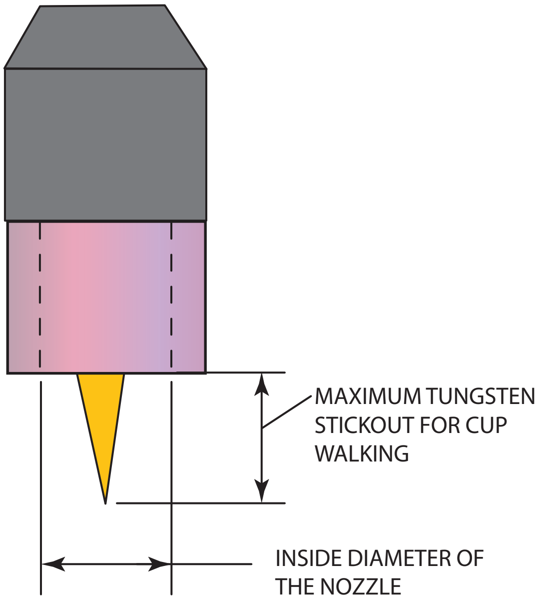

FIGURE 18-24 The maximum recommended tungsten extension for cup walking.

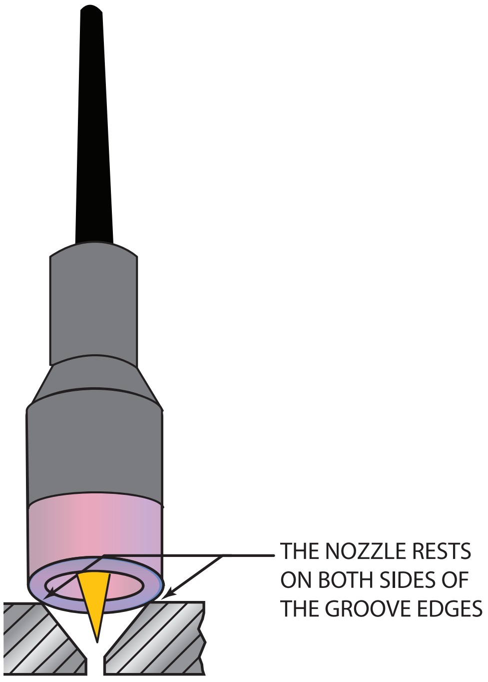

FIGURE 18-25 Rest the nozzle on the groove edges.

Because the filler rod is rested in the welding joint, it is important that it should be slightly larger in diameter than the root opening so it does not fall through the root during welding. For example, when welding on a pipe that has a 3/32-in. (2.4-mm) root opening, a 1/8-in. (3-mm) or larger filler rod should be used.

The outside edge of the nozzle must be sharp so it does not slip as it is stepped along the joint when the torch is moved in a figure-8 pattern, Figure 18-25. As the sharp corner of the nozzle wears down, it may begin to slip. When this happens, it can be turned so that another part of the nozzle edge can be used. Because the nozzle edge wears down, cup walking may require more frequent changes of the nozzle than does the traditional GTA welding technique.

NOTE

For the best results with cup walking, you should use a high-temperature ceramic nozzle such as silicon nitride.

Cup Walking Technique

During cup walking, both the nozzle and the filler metal are rested on the pipe joint, **Figure 18-26**. The nozzle is held firmly against the pipe while only very light pressure is applied to the filler metal. The firm cup pressure helps the edge of the nozzle to grip the pipe so that it can be stepped forward as the figure 8 pattern is made. The firm pressure does not cause a problem with most piping materials; however, on softer metals such as aluminum the nozzle can leave marks that can be deep enough to

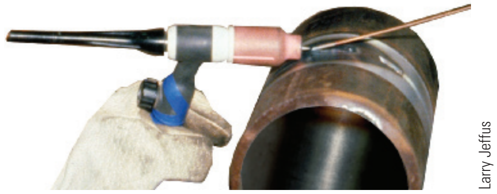

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FIGURE 18-26 Resting the cup and filler metal on the pipe groove.

be considered defects. So, when cup walking is used on aluminum pipe, very light pressure must be used.

Too much pressure on the filler rod can cause it to push through the molten weld metal, causing root surface problems such as excessive root penetration or buildup. The rod is held parallel to the joint so that the end is just at the leading edge of the molten weld pool. The end of the rod is melted by the figure-8 movement of the torch and flows into the leading edge of the molten weld pool.

The figure-8 movement, **Figure 18-27A**, is made so that one edge of the nozzle is lifted off of the pipe joint edge, **Figure 18-27B**, and moved slightly forward, **Figure 18-27C**. Each time the torch moves through the figure 8, it steps slightly forward. Moving your whole arm is less tiring than moving just your wrist, **Figure 18-28**.

After the weld has been built up with the root pass and several filler passes, the torch nozzle will begin touching the weld face as well as both sides of the groove. At this time you should change to a larger diameter nozzle to make it easier to walk the cup. The walking technique remains the same even though now three points are being contacted by the torch nozzle.

The nozzle will have only one contact point as the cover pass is welded. Some welders will use an even larger nozzle for the cover pass while others may stay with the same nozzle size they used for the last filler pass.

PRACTICE WELDS

Practice welds in this chapter should be made using both the traditional method of adding filler metal and the cup walking technique. Both techniques are important, and as a skilled pipe welder you must be proficient with each.

PRACTICE 18-2

Root Pass, Horizontal Rolled Position (1G)

For this practice, you will need a properly set-up and adjusted GTA welding machine, proper safety protection, two or more pieces of 3-in. (76-mm) to 10-in. (254-mm) diameter schedule 40 mild steel pipe prepared with single V-grooved joints and tack welded as described in Practice 18-1, and a few filler rods with 1/16-in. (2-mm), 3/32-in.

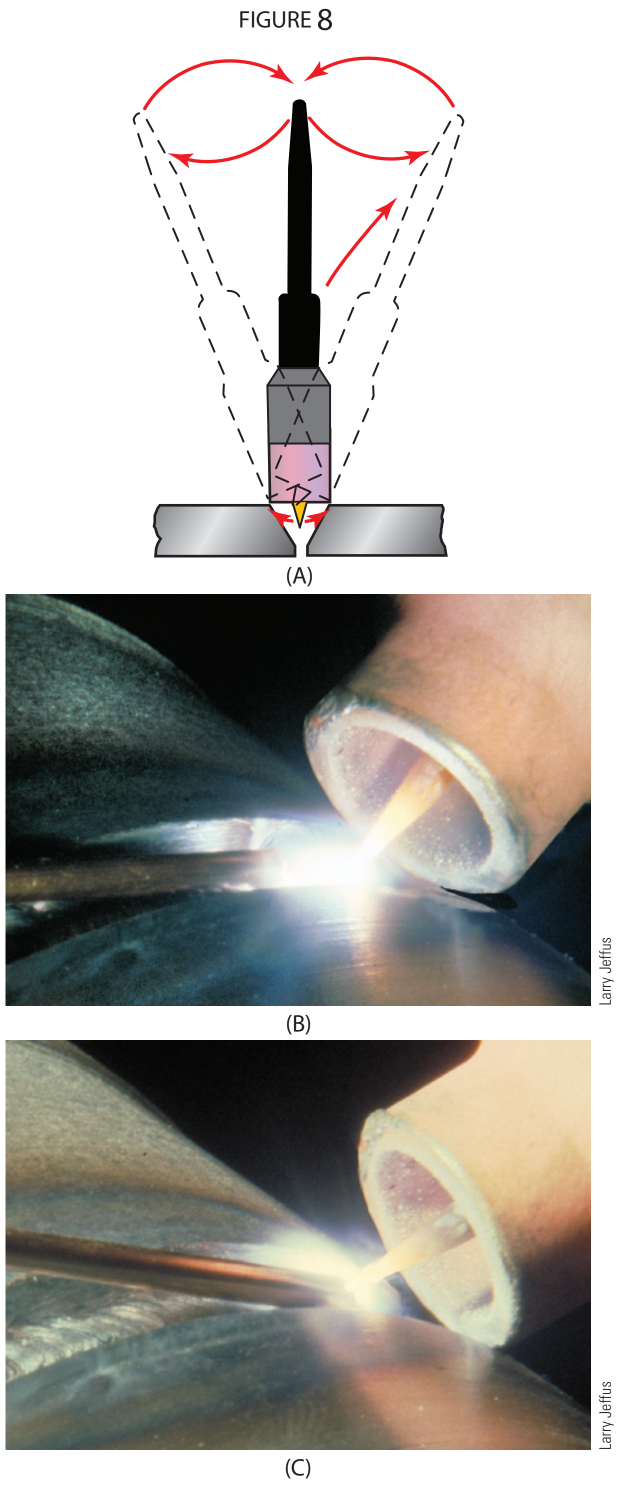

FIGURE 18-27 Moving the top of the torch in a figure 8 pattern (A) first lifts one side of the cup (B) and lets you move it slightly forward. Then, the other side of the cup is lifted (C) and it is moved forward.

(2.4-mm), and 1/8-in. (3-mm) diameters. You will make a root welding pass on a pipe in the horizontal rolled (1G) position, **Figure 18-29**.

Place the pipe securely in an angle iron vee block. Using the same procedure as practiced for the tack welds, place the cup against the beveled sides of the joint with the torch at a steep angle (refer to Figure 18-20). Start the weld near the 3 o'clock position and weld toward the 12 o'clock position. Stop welding just past the 12 o'clock position and roll the pipe. Starting the weld above the 3 o'clock position is easier, and starting the weld below this position is harder, **Figure 18-30**. Brace yourself against the pipe and try moving through the length of the weld to determine if you have full freedom of movement.

Hold the filler rod close to the pipe so it is protected by the shielding gas, thus preventing air from being drawn into the inert gas around the weld. The end of the rod must be far enough away from the starting point so it will not be melted immediately by the arc. However, it must be close enough so that it can be seen by the light of the arc.

Cup walking the torch along a groove can be practiced without welding power so you can see how to move the torch. This technique can be used on most GTA groove welds in pipe or plate, **Figure 18-31**. A skilled welder can also use it on the filler and cover passes.

When you are comfortable and ready to start, lower your helmet. Switch on the welding current by depressing the foot or hand control. Slowly pivot the torch until the arc starts. Increase the current to establish a new molten weld pool on both sides of the root face. Place the filler rod in the root of the weld as the torch is rocked from side to side and moved slowly ahead. The side-to-side motion can be used to walk the nozzle along the groove. The cup walking will ensure good fusion in both root faces and help make a very uniform weld, **Figure 18-32**. When walking the nozzle along the groove, the tip of the torch cap will make a figure-8 motion.

Watch the molten weld pool to make sure that it is balanced between both sides. If the molten weld pool is not balanced, then one side is probably not as hot, nor is it penetrating as well.

To ensure good fusion and penetration of the weld at the tack welds, or as the weld is completed, a special tie-in technique is required. Stop adding filler metal to the molten weld pool when it is within 1/16 in. (2 mm) of the tack weld. At this time the key hole will be much smaller or completely closed.

Continue to rock the torch from side to side as you move ahead. Watch the molten weld pool. It should settle down or sink in when the weld has completely tied itself to the tack weld. Failure to do this will cause incomplete fusion or cold lap at the root. To prevent crater cracks or lack of root penetration when restarting the weld stop your weld on top of the tack weld using one of the following techniques:

- Slowly decrease the welding current as you add more welding rod to fill the weld crater.
- Slowly decrease the welding power so that the molten weld pool tapers down.

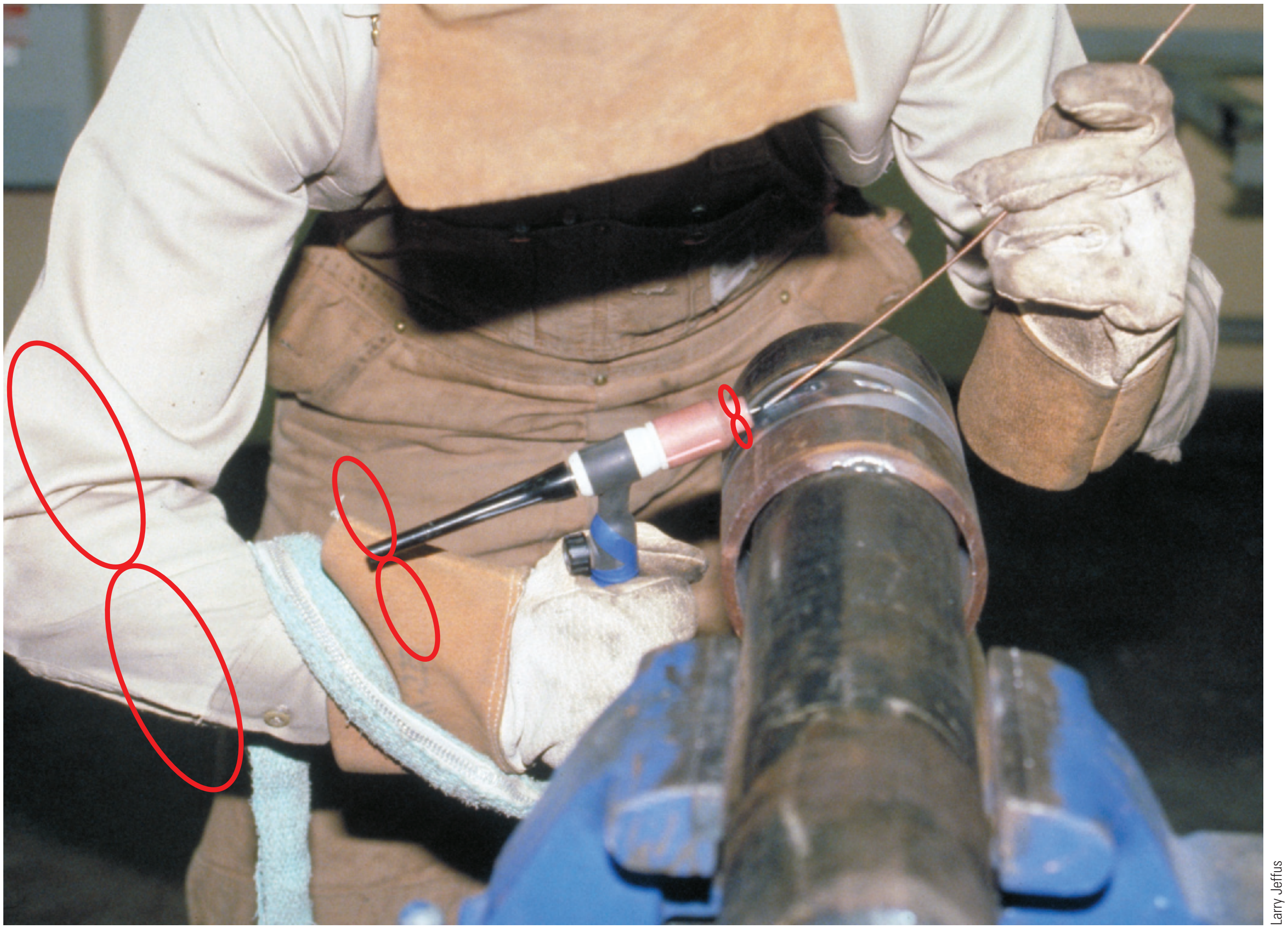

FIGURE 18-28 Moving your whole arm in the figure 8 pattern is less tiring than moving just your wrist.

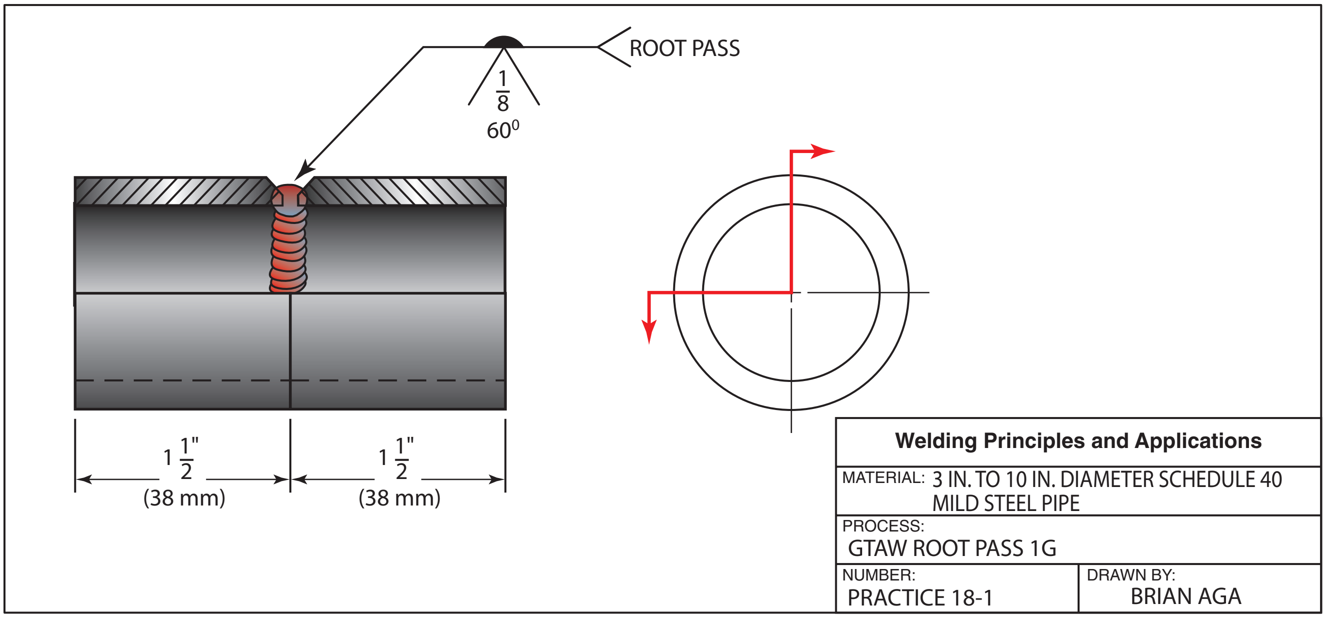

FIGURE 18-29 Root pass horizontal rolled position butt joint.

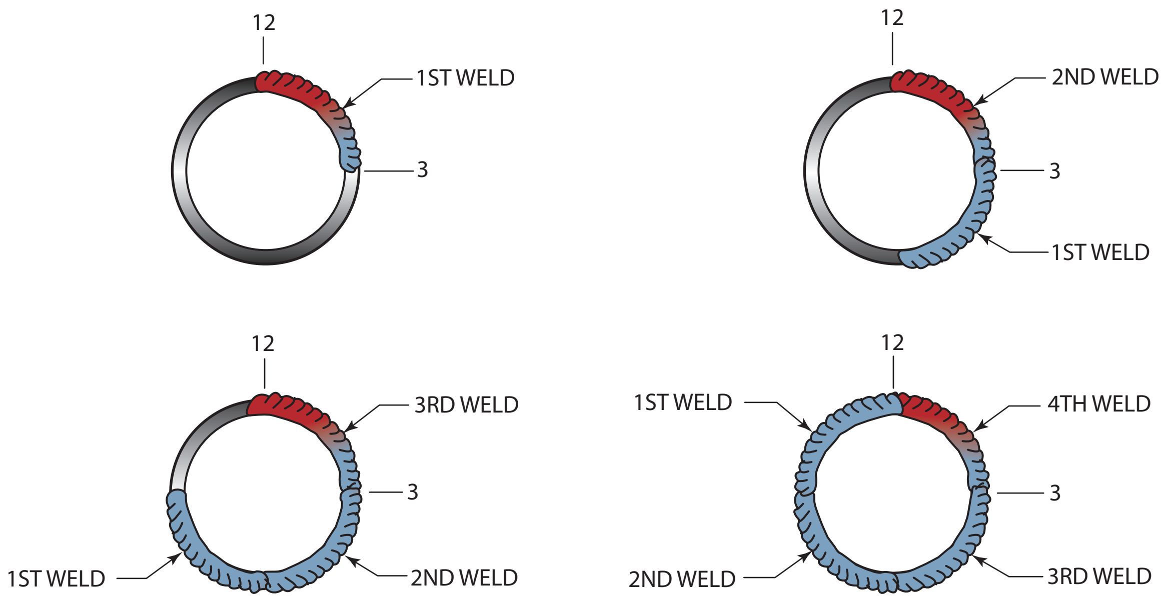

FIGURE 18-30 Welding sequence for 1G position.

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FIGURE 18-31 Practicing cup walking without the welding machine turned on.

- Leave the end of the filler rod stuck in the weld pool as it solidifies, **Figure 18-33**. When the weld is restarted, the filler rod will be melted free as the weld is continued.

After the weld is complete around the pipe, visually check the root for any defects. Repeat this practice as needed until it is mastered. Turn off the welding machine, shielding gas, and cooling water, and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

HOT PASS

A hot pass can be used to correct some of the problems caused by a poor root pass. It can be used to correct incomplete root fusion or excessive concavity of the root surface. The hot pass may be a hotter-than-normal filler pass.

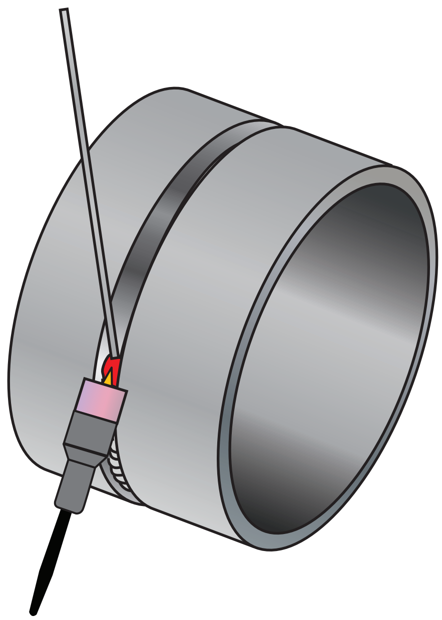

FIGURE 18-32 Increasing or decreasing the width of the torch movement can be used to control the sidewall fusion.

Normally, filler metal is added during the hot pass, but if the root pass is overly filled and cannot be ground back, then the hot pass may be made without adding filler metal all the time, **Figure 18-34**.

Root Surface

Concave root surfaces are generally caused by insufficient filler metal for the joint. To correct this condition, a hot filler pass is used to add both the needed metal and heat.

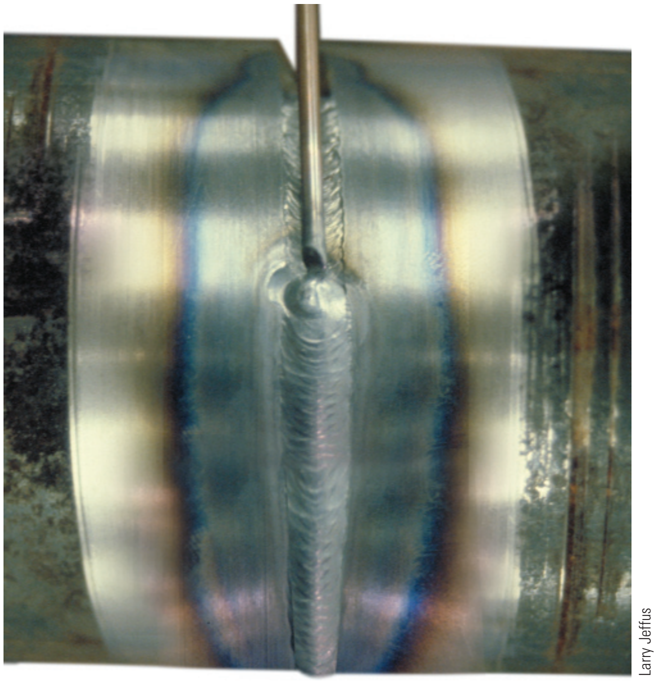

FIGURE 18-33 Leaving the filler metal fused to the weld pool makes it easier to continue the weld after you reposition yourself.

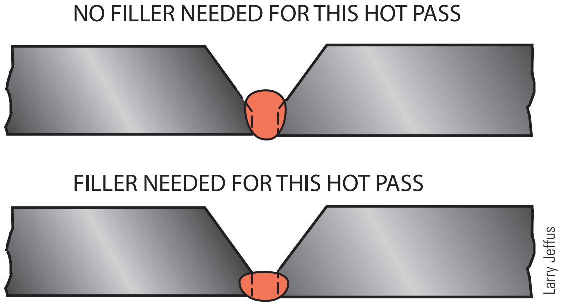

FIGURE 18-34 A hot pass can be used to correct incomplete root fusion or excessive concavity of the root surface.

During the weld, watch the molten weld pool surface to see when it sinks slightly (preferably equal to the needed reinforcement). Move the torch forward. Watch the molten weld pool sink and then add filler. Continue this process along the area of root concavity.

Lack of Root Fusion

Incomplete fusion generally is caused by insufficient heat and temperature for the joint. To correct this condition a hot pass is used with or without adding more filler metal. As before, watch the molten weld pool. When it sinks, move the torch ahead. Continue this process along the area of incomplete root fusion.

EXPERIMENT 18-1

Repairing a Root Pass Using a Hot Pass

Using a properly set-up and adjusted GTA welding machine, proper safety protection, two or more pieces of schedule 40 mild steel pipe 3 in. (76 mm) to 10 in. (254 mm) in diameter prepared with single V-grooved joints with poor root weld passes, and some filler rods with diameters of 1/16 in. (2 mm), 3/32 in. (2.4 mm), and 1/8 in. (3 mm), you will make a hot pass to correct defects in the root weld.

The first step is to determine the root weld defects and mark the location and type of defect on the outside of the pipe. Most defective root welds will have areas of one type of defect followed by another area of a different type of defect. This occurs most commonly as the student makes overadjustments to correct a problem or as the root opening and root face dimensions change.

Mark the groove with a soapstone or paint marker to indicate the type of defect below. It may be necessary to grind the root weld in the areas of the defects so that they can be repaired more easily with the hot pass. Place the pipe with the defect in the 12 o'clock welding position and deposit the weld. The hot pass may vary in size as it progresses around the pipe. The weld can go faster across areas that do not require root repair. Turn off the welding machine, shielding gas, and cooling water, and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 18-3

Stringer Bead, Horizontal Rolled Position (1G)

Using a properly set-up and adjusted GTA welding machine, proper safety protection, one or more pieces of mild steel pipe 3 in. (76 mm) to 10 in. (254 mm) in diameter, and some filler rods with diameters of 1/16 in. (2 mm), 3/32 in. (2.4 mm), and 1/8 in. (3 mm), you will make a straight stringer bead around a pipe in the horizontal rolled position.

Start by cleaning a strip 1 in. (25 mm) wide around the pipe. Brace yourself against the pipe so that you will not sway during the weld, **Figure 18-35**. The torch should have a slight upward slope, approximately 5° to 10° from perpendicular to the pipe surface, **Figure 18-36**. The filler wire should be held so that it enters the molten weld pool from the top center at a right angle to the torch.

Start the weld near the 3 o'clock position and weld upward to a point just past the 12 o'clock position. To minimize stops and starts, try to make the complete weld without stopping. With the power off and your helmet up, move the torch through the weld to be sure you have full freedom of movement.

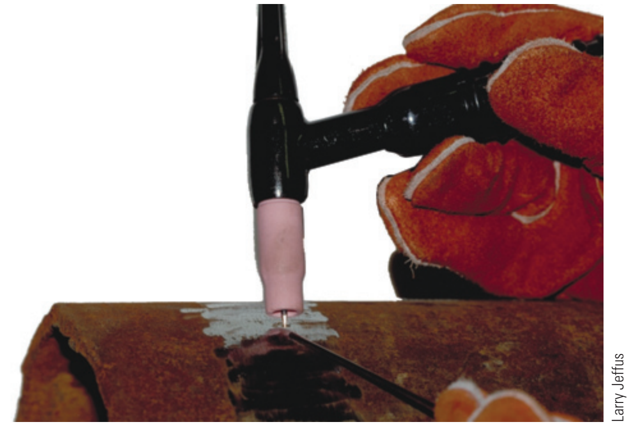

FIGURE 18-35 Bracing the gloved hand against the pipe can help you control both the arc and filler metal. Note the precleaning of the pipe.

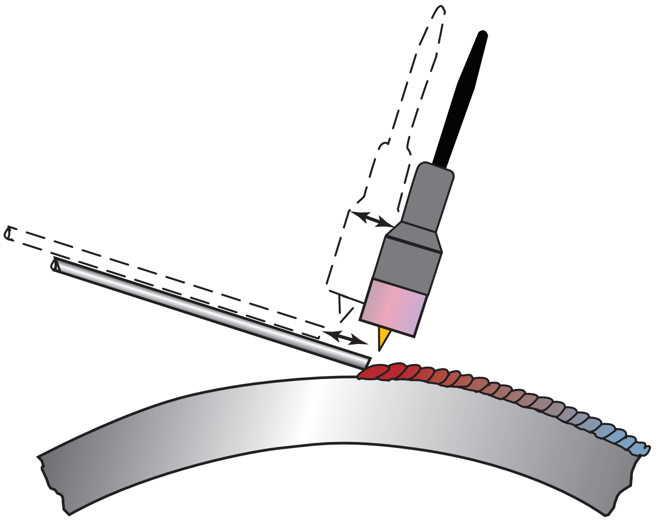

FIGURE 18-37 The torch and filler rod are moved back and forth together.

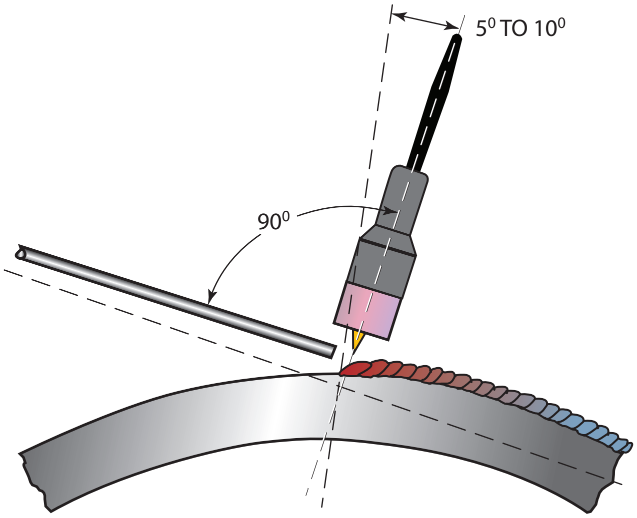

FIGURE 18-36 Alignment of torch and rod for pipe welding.

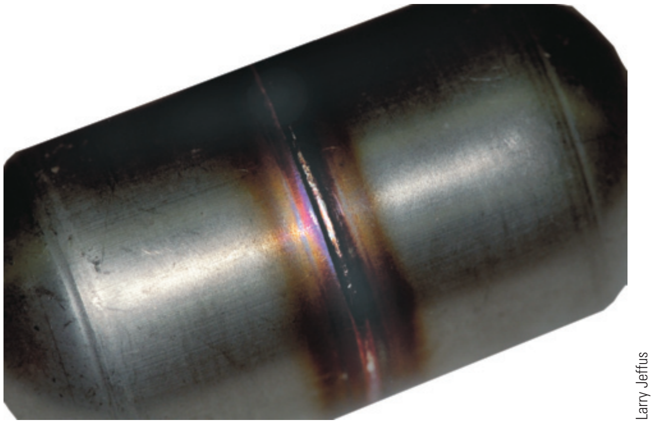

FIGURE 18-38 Keeping your movement and adding filler metal consistently will help you make a uniform weld bead.

With the torch held in position so that the tungsten is just above the desired starting spot, lower your helmet. Start the welding current by depressing the foot or hand control switch. Establish a molten weld pool and dip the filler rod in it. Use a straight forward and back movement with both the torch and rod, **Figure 18-37** and **Figure 18-38**. However, never move farther ahead than the leading edge of the molten weld pool. Too large of a movement will lead to inadequate molten weld pool coverage by the shielding gas. The short motion is to allow the rod to be melted into the weld pool without the heat from the arc melting the rod back, **Figure 18-39**.

As the weld progresses from a vertical position to a flat position, the frequency of movement and pause times will change. Generally, the more vertical the weld, the faster the movement and the shorter the pause times. As the weld becomes flatter, the movement is slower and the pause times

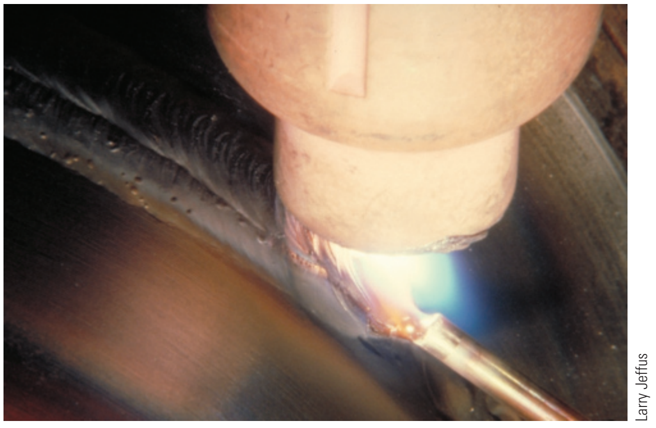

FIGURE 18-39 The filler rod should be melted in the molten weld pool but not allowed to melt and drop into the weld pool.

are longer, **Figure 18-40**. In the vertical position, gravity tends to pull the weld toward the back center of the bead. This makes a high crown on the weld with the possibility of undercutting along the edge. Flatter positions cause the weld to be pulled out, resulting in a thinner weld with less apparent reinforcement, **Figure 18-41**.

When the weld reaches the 12 o'clock position, stop and roll the pipe. To stop, slowly decrease the current and add welding rod to fill the weld crater. Keep the torch held over the weld until the postflow stops. This precaution will prevent the air from forming oxides on the hot weld bead.

After the weld is complete around the pipe, it should be visually inspected for straightness, uniformity, and defects. Repeat the process until you can consistently make the weld visually defect free. Turn off the welding machine, shielding gas, and cooling water, and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

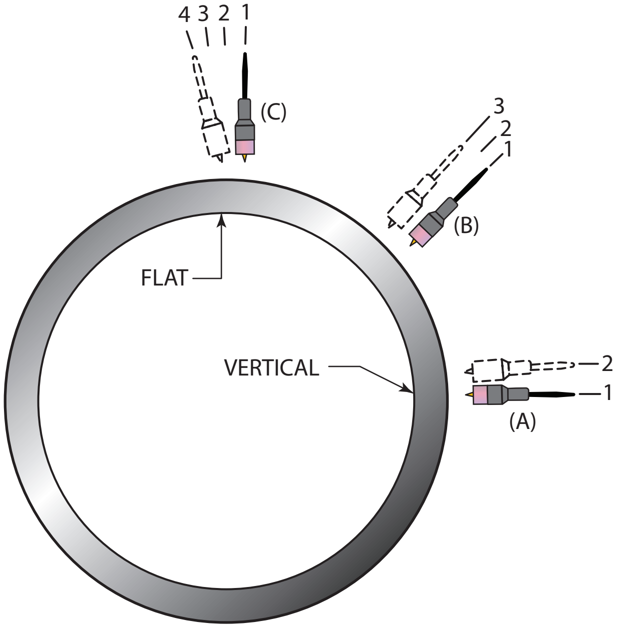

FIGURE 18-40 Counting to oneself is one way of setting the welding rhythm. As the weld progresses from vertical (A) through (B) to flat (C), the rhythm slows and the torch angle changes.

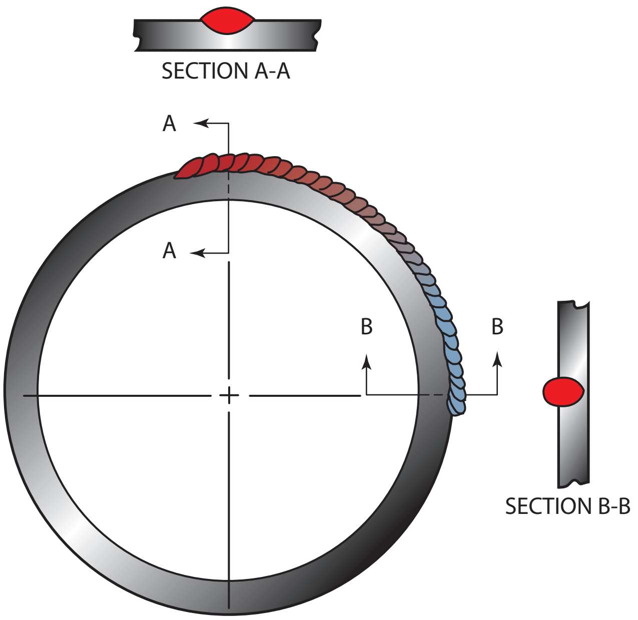

FIGURE 18-41 The weld bead contour, if uncontrolled, can change a great deal from the vertical to flat positions.

PRACTICE 18-4

Weave and Lace Beads, Horizontal Rolled Position (1G)

Using a properly set-up and adjusted GTA welding machine, proper safety protection, one or more pieces of mild steel pipe 3 in. (76 mm) to 10 in. (254 mm) in diameter, and some filler rods with diameters of 1/16 in. (2 mm), 3/32 in. (2.4 mm), and 1/8 in. (3 mm), you will make a straight weave or lace bead around a pipe in the horizontal rolled position.

Start by cleaning a strip 1 in. (25 mm) wide around the pipe. Brace yourself and check to see that you have enough freedom of movement to make a weld from the 3 o'clock to 12 o'clock positions. Hold the torch with a 5° to 10° upward angle. The filler rod is to be held at a right angle to the torch.

Lower your helmet and establish a molten weld pool. Add filler metal as you move the torch to the side. Slowly build a shelf to support the molten weld pool or bead, **Figure 18-42**.

To make a weave bead, move the torch in a "C," "U," or zigzag pattern across the molten weld pool. The pattern should be no wider than one-half the diameter of the cup. Too large of a weave means that part of the molten weld pool will not have a cover of the shielding gas. This results in atmospheric contamination of the molten weld pool.

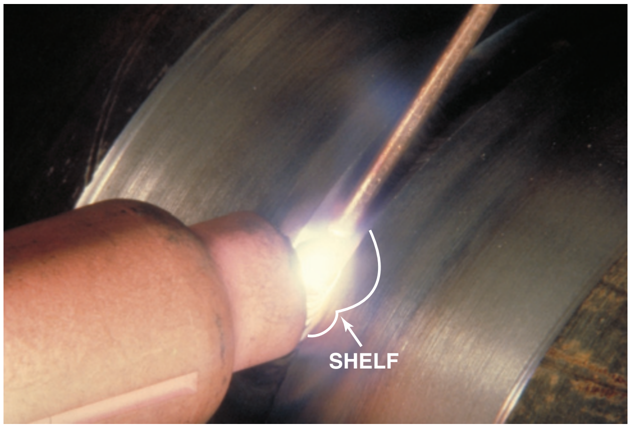

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FIGURE 18-42 The shelf will support the molten pool during the vertical portion of the weld.

To make a lace bead, slowly move the torch in a zigzag pattern across the weld bead. The molten weld pool should never be larger than that for a stringer bead. A lace bead can be made any desired width because the small molten weld pool is always protected from atmospheric contamination.

Continue the weave or lace bead up the pipe until you reach the top. To stop slowly, lower the current and add welding rod until the crater is filled. Turn the pipe and continue the bead around the pipe.

After the bead is complete around the pipe, visually inspect it for uniformity in width and reinforcement. The bead must also be free of visible defects. Repeat the process until you can consistently make the weld visually defect free. Turn off the welding machine, shielding gas, and cooling water, and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

FILLER PASS

The filler pass is the next weld layer(s) to be made after the hot pass. The filler pass should be used to fill the groove quickly. There should be complete fusion but little penetration. Deep penetration serves only to slow the completion of the joint and to subject the pipe to more heat (BTUs) and temperature (degrees) than needed, **Figure 18-43**.

Often only one GTA filler pass is used to protect the thin root pass from burnthrough. Because of the longer welding time required for the GTA process, pipe joints are often completed using another process. Most other processes, such as SMAW, GMAW, or FCAW, are much hotter and most likely will burn through the root without the added protection of a GTA hot pass and filler pass.

PRACTICE 18-5

Filler Pass (1G Position)

Using a properly set-up and adjusted GTA welding machine, proper safety protection, two or more pieces of 3-in. (76-mm) to 10-in. (254-mm) diameter schedule 40 mild steel pipe prepared with single V-grooved joints and with a root pass (as described in Experiment 18-1), and some filler rods with 1/16-in. (2-mm), 3/32-in. (2.4-mm), and 1/8-in. (3-mm) diameters, make a filler welding pass in the groove in the horizontal rolled (1G) position.

- Place the pipe securely in an angle iron vee block.
- Using the same procedure practiced for the tack welds and root pass, place the cup against the beveled sides of the joint with the torch at a 5° to 10° upward angle.
- Brace yourself and check for full freedom of movement along the welded joint.
- Start the weld near the 1 o'clock position and end just beyond the 12 o'clock position.
- Lower your helmet and establish a molten weld pool. Using the same forward and backward motion that you developed when making the stringer bead in Practice 18-3, add the filler metal at the top center of the molten weld pool until the bead surface is flat or slightly convex. Adding too little filler to this pass may result in burnthrough if another process is used to complete the joint. The filler pass should have as little penetration as possible so that the maximum reinforcement can be added with each pass. Deep penetration beyond the depth required to fuse the weld to the bevel and hot pass will slow the joint fill-up rate.
- To stop the molten weld pool, slowly decrease the current and add rod to fill the weld crater. Another method is to slowly decrease the current and pull the bead up on the beveled side of the joint, **Figure 18-44**.
- Turn the pipe and repeat this bead until the joint is filled within 1/16 to 1/8 in. (2 to 3 mm) of the pipe surface, **Figure 18-45**.

Turn off the welding machine, shielding gas, and cooling water, and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

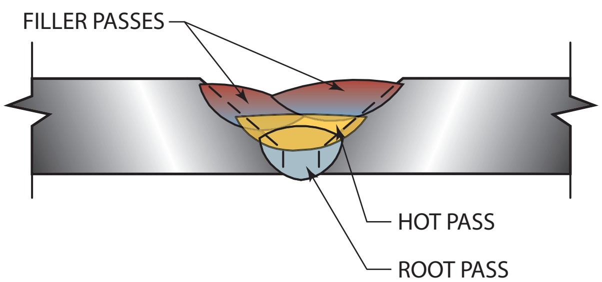

FIGURE 18-43 The filler pass(es) should fill the groove as much as possible but not more than to a 1/4 in. (6 mm) thickness at a time.

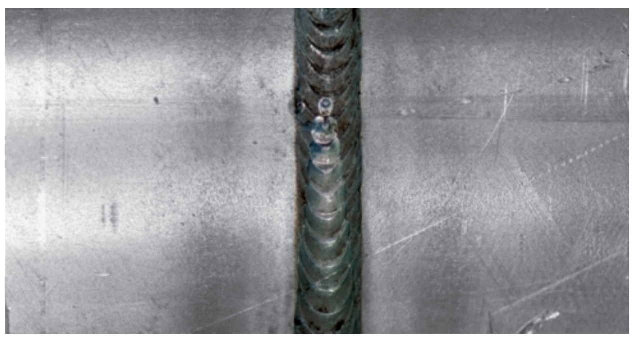

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FIGURE 18-44 Taper down the weld when completing it to avoid a large crater.

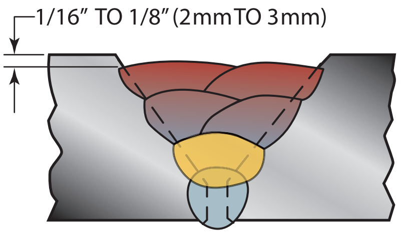

FIGURE 18-45 The filler pass should not fill the groove flush with the surface, but should leave space for the cover pass.

COVER PASS

The stringer bead can be continued to cap the weld. If this technique is used, then the bead should overlap the pipe surface no more than 3/32 in. (2.4 mm). Total reinforcement must not exceed 3/32 in. (2.4 mm) on pipe having walls less than 3/8 in. (10 mm) thick, **Figure 18-46**.

After the weld is complete, visually inspect it for uniformity in width and reinforcement and for any defects.

PRACTICE 18-6

Cover Pass (1G Position)

Using a properly set-up and adjusted GTA welding machine, proper safety protection, two or more pieces of 3-in. (76-mm) to 10-in. (254-mm) diameter schedule 40 mild steel pipe that are single V-grooved and are welded flush with filler passes (as described in Experiment 18-1), and some filler rods with 1/16-in. (2-mm), 3/32-in. (2.4-mm), and 1/8-in. (3-mm) diameters, you will cap the weld with a cover pass made in the horizontal rolled (1G) position, **Figure 18-47**.

Using the same techniques and skill developed in Practice 18-5, make a cover pass. The weld should not be more than 3/32 in. (2.4 mm) wider than the groove and should have a buildup of no more than 3/32 in. (2.4 mm).

After the weld is complete, visually inspect it for uniformity in width and reinforcement and for any defects. Repeat the process until you can consistently make the weld visually defect free. Turn off the welding machine, shielding gas, and cooling water, and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 18-7

Stringer Bead, Horizontal Fixed Position (5G)

Using the same equipment, setup, and materials as listed in Practice 18-1, make a straight stringer bead around an ungrooved pipe in the horizontal fixed position.

- Clean a strip 1 in. (25 mm) wide around the pipe.
- Mark the top for future reference and clamp the pipe at a comfortable work height.
- Brace yourself so you are steady and move through the weld to make sure that you have freedom of movement.
- Lower your helmet and establish a molten weld pool at the 6 o'clock position. Keep the molten weld pool size small so that it will stay uniform.

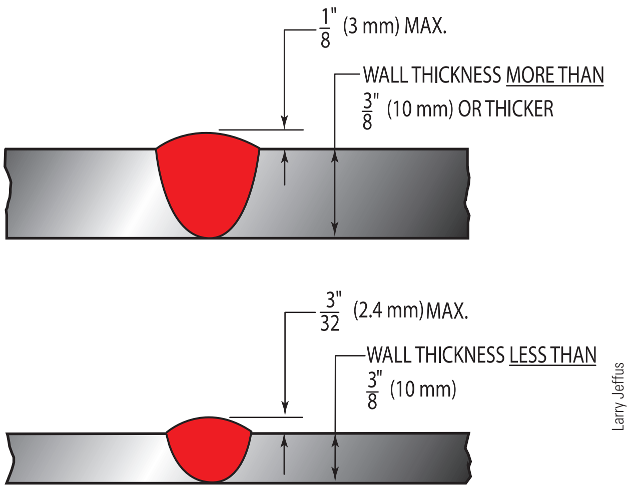

FIGURE 18-46 Excessively large weld beads prevent the pipe from uniformly expanding under pressure. This restriction from expanding can cause a failure to occur in or near the weld.

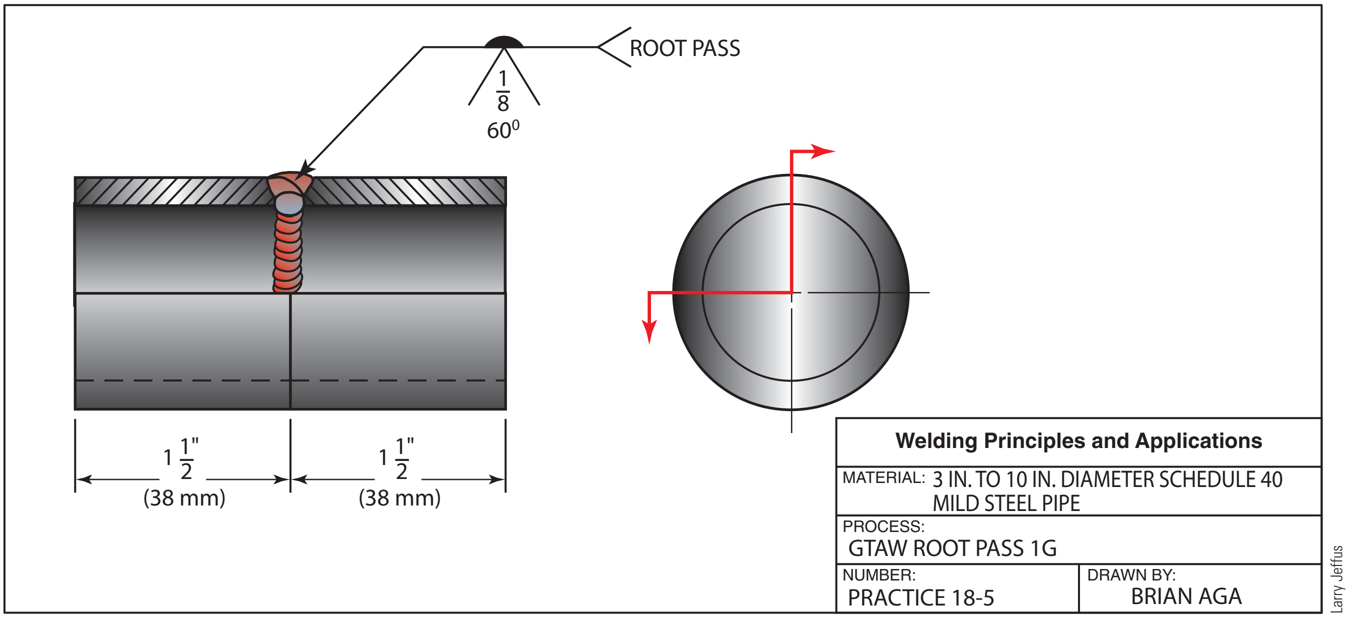

FIGURE 18-47 Butt joint in the 1G position.

- Dip the filler metal into the front leading edge of the molten weld pool.
- Move the torch forward and backward as the rod is added. The frequency of movement will increase as the weld becomes more vertical.
- Continue the weld without stopping, if possible, to the 12 o'clock position.
- Repeat the weld up the other side in the same manner.

When the weld is complete, visually inspect it for straightness and uniformity, and for any defects. Repeat the process until you can consistently make the weld visually defect-free. Turn off the welding machine, shielding gas, and cooling water, and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

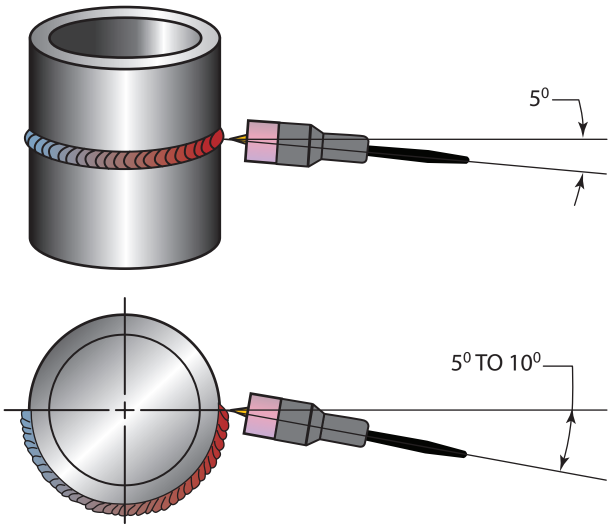

FIGURE 18-48 When making a straight stringer bead around a pipe in the horizontal fixed position, hold the torch at a 5° angle from horizontal and 5° to 10° from perpendicular to the pipe.

PRACTICE 18-8

Stringer Bead, Vertical Fixed Position (2G)

Using the same equipment, setup, and materials as listed in Practice 18-1, make a straight stringer bead around a pipe in the vertical fixed position.

- Hold the torch at a 5° angle from horizontal and 5° to 10° from perpendicular to the pipe, **Figure 18-48**. This will allow good visibility and simplify the process of adding the rod at the top of the bead.
- Establish a small molten weld pool and filler along the top front edge, **Figure 18-49**. Gravity will tend to pull down the metal, especially if the molten weld pool becomes too large. When the molten weld pool sags, undercut appears along the top edge of the bead. A slight "J" pattern may help to control weld bead sag by making a small shelf to support the molten weld pool while it cools.

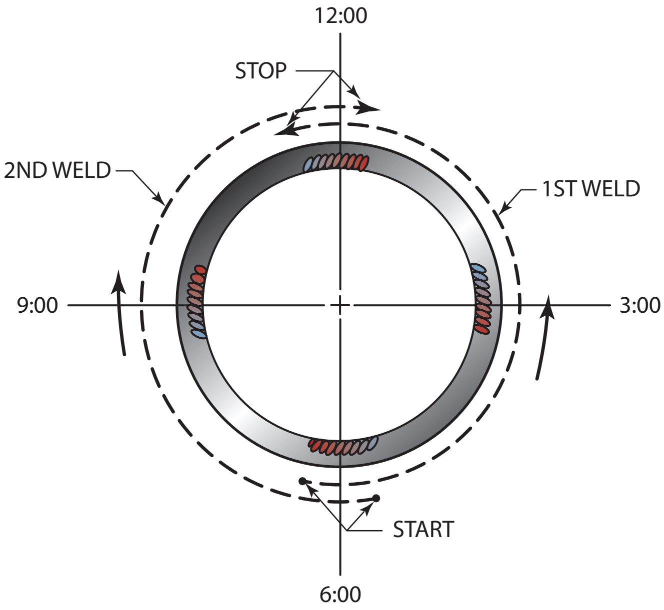

FIGURE 18-49 Tack welds on pipe in 5G position and the welding sequence.

When the weld is completed, visually inspect it for uniformity, straightness, and any defects.

Repeat the process until you can consistently make the weld free of visual defects. Turn off the welding machine, shielding gas, and cooling water, and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 18-9

Stringer Bead on a Fixed Pipe at a 45° Inclined Angle (6G Position)

Using the same equipment, setup, and materials as listed in Practice 18-1, make a straight stringer bead around a fixed, ungrooved pipe at a 45° inclined angle.

- Starting at the 6:30 o'clock position with the torch at a slight downward angle, establish a small molten weld pool, **Figure 18-50**.
- Add the rod at the upper leading edge of the molten weld pool. A slight "J" pattern can help control the bead size. As the weld progresses around the pipe, the weld becomes more vertical. The rate of movement should increase.
- Keep the size of the weld small so it can be controlled.

After the weld is complete, visually inspect it for uniformity and for any defects. Repeat the process until you can consistently make the weld free of visual defects. Turn off the welding machine, shielding gas, and cooling water, and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

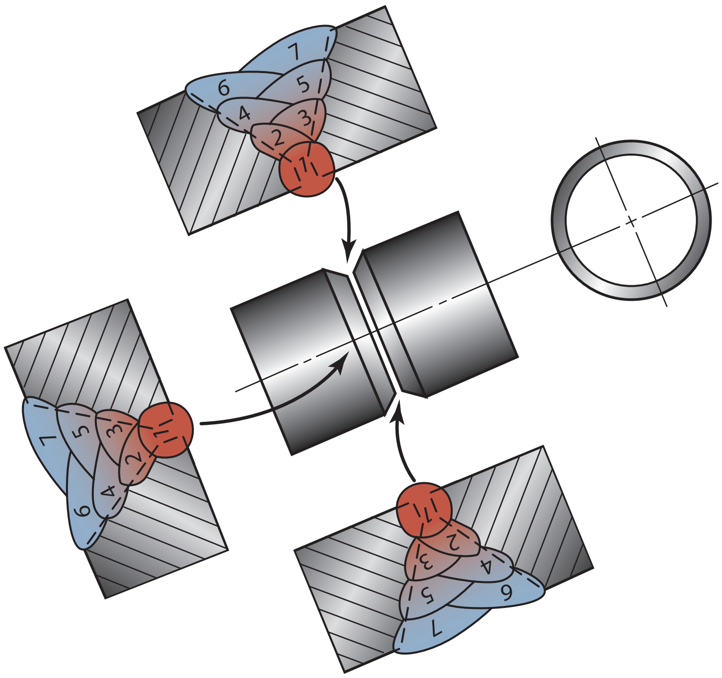

FIGURE 18-50 6G welding bead sequence.

Summary

Often gas tungsten arc welding of pipe is considered to be the most prestigious of the welding processes. It has obtained this status primarily because of where much of the GTA welding of pipe is done. High-quality gas tungsten arc pipe welding is performed on nuclear reactors, in petrochemical plants, and in the fabrication of the international space station. There are many other applications for this process and they enjoy the same prestige, although they are often not nearly as critical.

The constantly changing weld position is the most challenging part of gas tungsten arc welding. Learning how to gently rest the nozzle on the surface of the pipe as you make your welds can be a tremendous benefit. The ceramic cup does not slide very easily on the metal surface, so it takes a very light touch to learn this technique. Once you have developed this light touch, you can begin working on the more complicated cup walking technique. A skilled welder using the cup walking technique can produce welds that appear machine-like in quality.

Access to the welding joint can be an additional challenge that the GTA welder must overcome, **Figure 18-51**. The limited access on these boiler tubes is typical of the restricted access that can be found in both new and repaired GTA welding. Thousands of these restrictive access welds can be required to repair and/or update a power plant boiler, **Figure 18-52**. Each weld must pass inspection because any weld that fails can result in the plant having to be shut down for repair work.

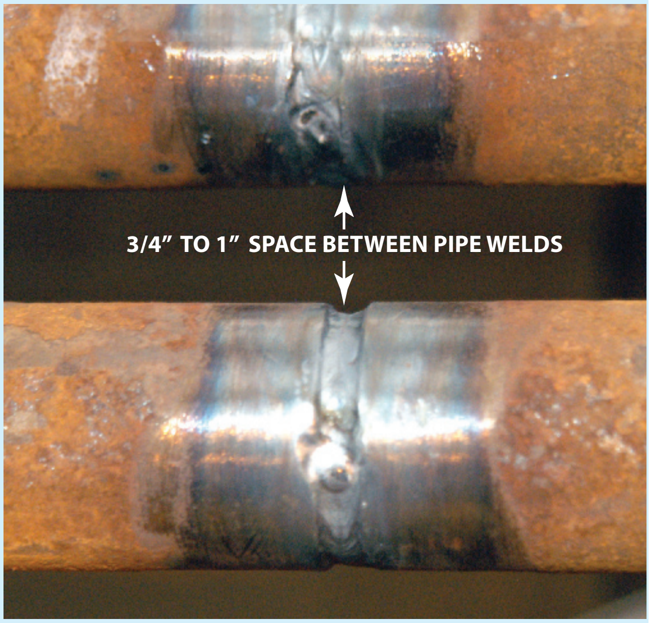

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FIGURE 18-51 Restricted access during welding can challenge a welder's skills.

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FIGURE 18-52 Typical restricted space on boiler tube welds.

Review

1. What types of industries require GTAW-quality pipe welds?
2. What are the grooves most often used for welding on mild steel pipe?
3. What condition must the prepared edges of a pipe be in before welding?
4. How is the depth of root penetration measured?
5. What problem can incomplete fusion cause?
6. What are the common causes of a concave root surface?
7. What problems can excessive root reinforcement cause?
8. What can cause root contamination?
9. What gases are used as backing gases?
10. How long would it take to purge a 15-ft section of 6-in. diameter pipe using a flow rate of 35 cfh?

11. How long would it take to purge a 10-mm section of a 20-cm diameter pipe using a flow rate of 17 L/min?
12. How can filler metal be added to make a root pass?
13. What information must be supplied when ordering consumable inserts?
14. How is the tack weld ended so that it will not crack?
15. What is the 1G pipe position?
16. After the weld is set up and ready to begin, how might the welder want to check for freedom of movement?
17. What type of weld can be made using the nozzle walking technique?
18. What two problems can be corrected by a hot pass?
19. Why must you brace yourself when making a weld?
20. What can happen to the weld pool if the torch movement is too long?
21. What technique should be used when stopping a weld?
22. What is the maximum width that a weave pattern should be?
23. Why should the filler pass penetration be limited in depth?
24. How much filler metal should be added to a filler bead?
25. What is the 5G pipe position?
26. How should the torch be held to allow good visibility on a 2G weld?
27. Why are stringer beads in the 6G position kept small?

Chapter 19

Gas Tungsten Arc Welding Plate and Pipe AWS SENSE Certification

OBJECTIVES

After completing this chapter, the student should be able to

- explain the weld specimen acceptance criteria for butt, lap, and tee joints.
- explain how to perform mechanical testing of weld specimens.
- demonstrate GTA welding skills needed to make acceptable welds in thin gauge mild steel, stainless steel, and aluminum in all positions.
- demonstrate GTA welding skills needed to make acceptable pipe welds in 2G, 5G, and 6G positions in mild steel, stainless steel, and aluminum pipe and tubing.

KEY TERMS

free bend test

lace bead

visual inspection (VT)

visual inspection acceptance criteria

INTRODUCTION

The GTA welding process is used to produce welds of the highest quality. The practices in this chapter are designed to further develop your GTA welding skills for plate and pipe welding that you learned in Chapters 17 and 18.

GTA SHEET WELDS

The AWS SENSE Level I Workmanship Qualifications test requires GTA welders to be able to make butt welds in the vertical up, horizontal, and overhead positions; intermittent lap welds in the horizontal and overhead positions; and tee welds in the horizontal and vertical up positions. These SENSE Level I GTA sheet welds are all made on a fabrication that you must make. The skills that you must have to successfully complete these qualification tests are safety, print reading, material layout, plasma arc cutting, fitting, and welding. This chapter will help you develop the welding skills required to make all of the required welds. Chapter 2 covers safety. Chapter 8 covers plasma arc cutting skills. Chapter 21 covers print reading. Chapter 22 covers welding symbols. Chapter 23 covers fabrication skills. Chapter 24 covers the specifications and welding procedures required for the workmanship standard.

GTA TUBING WELDS

The AWS SENSE Level II Workmanship Qualification test requires GTA welders to be able to make square groove butt welds with and without a backing ring in the 2G and 5G positions in thin wall small diameter mild steel, stainless steel, and aluminum tubing.

AWS SENSE GTA SHEET PRACTICE WELDS

The butt joint layout and test specimen locations are shown in **Figure 19-1**. The lap joint layout and test specimen locations are shown in **Figure 19-2**. The tee joint layout and test specimen locations are shown in **Figure 19-3**.

Weld Inspection and Testing

All the welds must pass **visual inspection (VT)** based on the criteria for each type of weld. Mechanical testing of these GTA welds is not required for these workmanship samples. The section on mechanical testing is just designed to aid students in evaluating their welds.

Butt Joint Welds

The **visual inspection acceptance criteria** for the butt joints are:

- no cracks,
- welds must have complete joint fusion,
- 100% root penetration,
- maximum face and root reinforcement is 1/8 in. (3.2 mm),
- maximum of one porosity per 1 in. (25 mm) of weld that is no larger than 25% of the base metal thickness, and
- no undercut greater in depth than 15% of the base metal thickness.

Fillet Welds, Lap and Tee Joints

The visual inspection acceptance criteria for the lap and tee joint fillet welds are:

- no cracks,
- welds must have complete joint fusion,
- maximum weld size 1/8 in. (3.2 mm),
- maximum face and root reinforcement is 1/8 in. (3.2 mm),
- maximum of one porosity per 1 in. (25 mm) of weld that is no larger than 25% of the base metal thickness, and
- no undercut greater in depth than 15% of the base metal thickness.

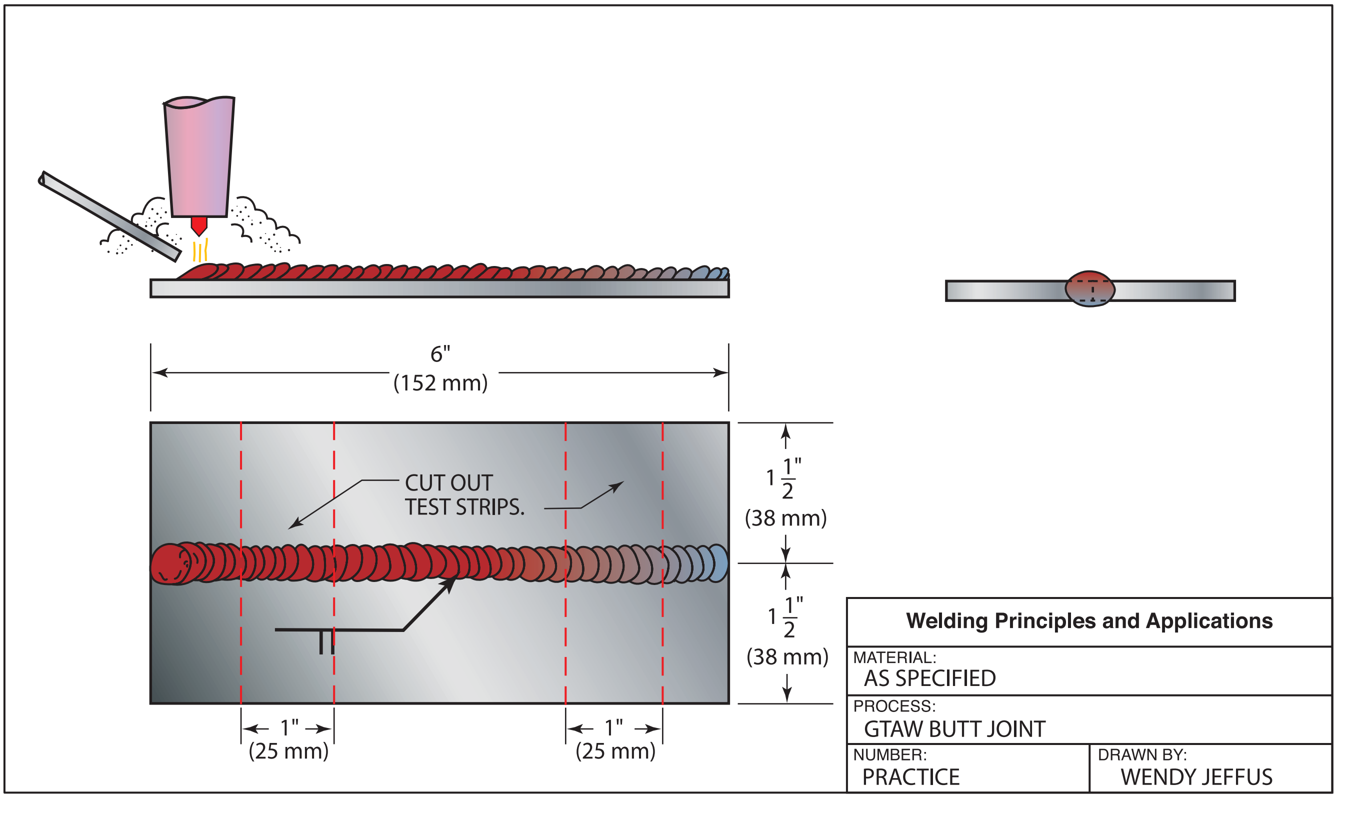


FIGURE 19-1 Butt joint layout and test specimen locations.

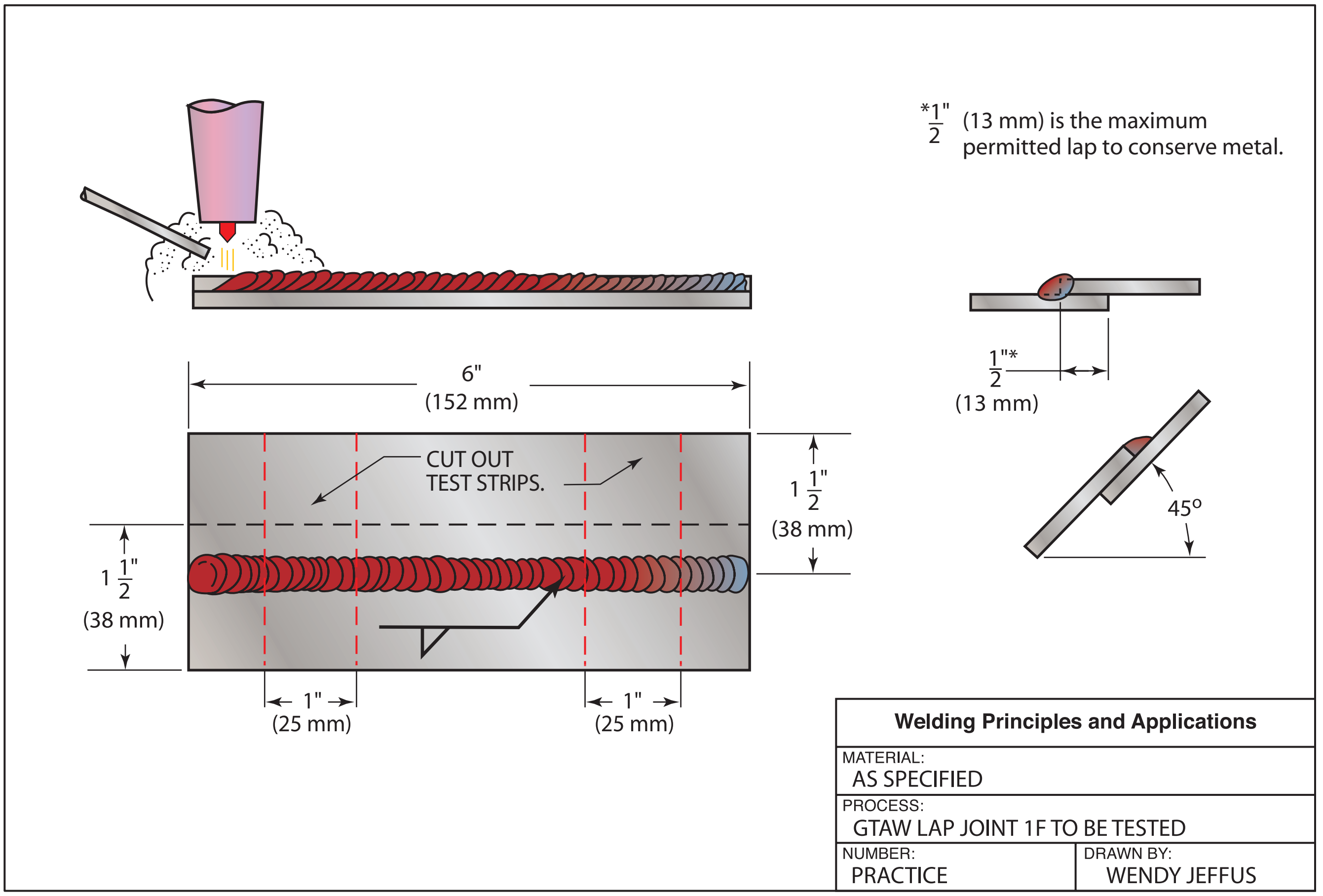


FIGURE 19-2 Lap joint layout and test specimen locations.

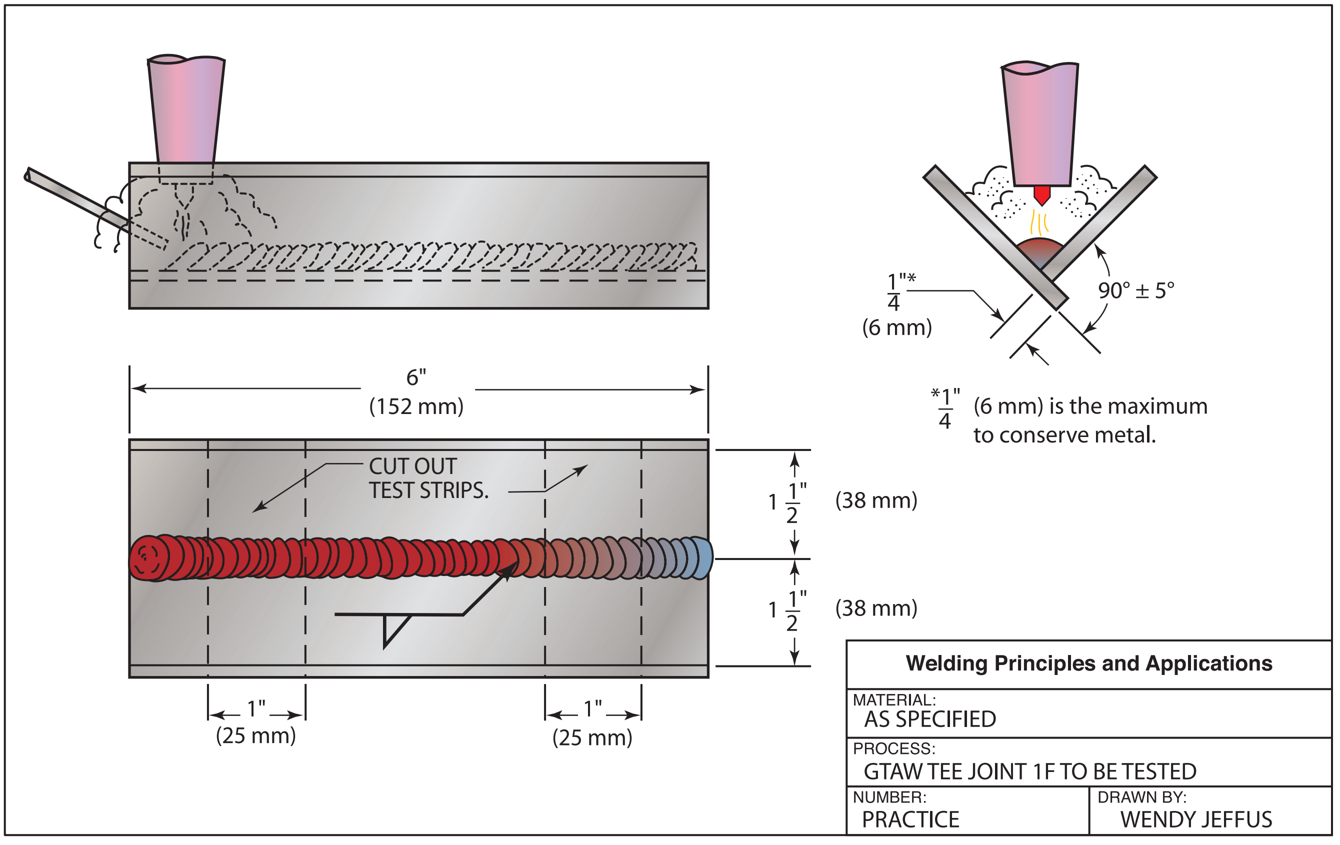


FIGURE 19-3 Tee joint layout and test specimen locations.

Tubing Welds

The visual inspection acceptance criteria for the tubing welds are:

- no cracks,
- welds must have complete joint fusion,
- 100% root penetration,
- maximum weld reinforcement is 1/8 in. (3.2 mm),
- maximum root face concavity is 1/16 in. (1.6 mm),
- weld surface must be at least flush with the outside of the pipe surface,
- weld face must have a smooth uniform transition from the sides of the weld to the weld face,
- maximum of one porosity per 1 in. (25 mm) of weld that is no larger than 25% of the base metal thickness,
- no undercut greater in depth than 1/32 in. (0.8 mm) and,
- all weld craters must be filled.

NOTE

A weld gauge or set of weld gauges should be used to make the measurements for the above acceptance standards, **Figure 19-4**.

MECHANICAL, DESTRUCTIVE TESTING

Mechanical testing is not required for these GTA AWS SENSE qualification tests. The **free bend test** is only designed to help you identify any root problems that might exist in your weld. This test does not have a pass or fail standard; it is just to help you see if you need to make any changes in the way you are welding the joints.

The 1-in. (25 mm) strips of the finished weld are cut out using a saw or thermal cutting process. The strips are placed in a vise and bent using a ball-peen hammer until the root of the weld is stretched, **Figure 19-5**. Observe the root of the weld to see if the weld had complete fusion.

FIGURE 19-4 Visual weld inspection kit.

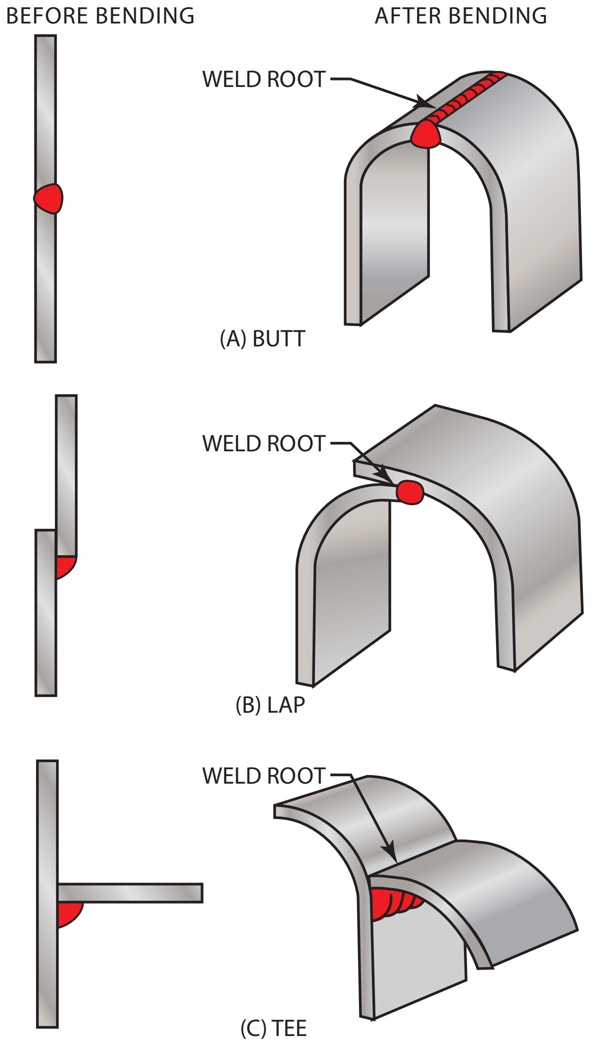


FIGURE 19-5 Free bend test.

FILLER METAL

Each of the mild steel and austenitic stainless steel practices allows some flexibility in the selection of filler metal to be used. Chapter 27, *Filler Metal Selection*, can be used to help you make the selection of the filler metal you wish to use for these practices.

THINK GREEN

Even with lots of practice, everyone accidentally contaminates their tungsten by touching the molten weld pool or filler rod. Often it is possible to carefully grind off the contamination as a way of conserving tungsten. However, remember to always wear all the required PPE when grinding tungsten.

SHEET METAL PRACTICE WELDS

PRACTICE 19-1

Butt Joint, All Positions Using Mild Steel with 100% Joint Penetration to be Tested

For this practice, you will need a properly set-up and adjusted GTA welding machine, proper safety protection including all required PPE, ER70S-X filler rods 36 in. (0.9 m) long, ranging from 1/16 in. (2 mm) to 1/8 in. (3 mm) in diameter, two or more pieces of mild steel 6 in. (152 mm) long and ranging in thickness from 11 ga to 14 ga, 100% argon shielding gas, tungsten electrodes ranging from 1/16 in. (2 mm) to 1/8 in. (3 mm) in diameter, saw or thermal cutting torch, and a bench vise and ball-peen hammer, **Figure 19-6**.

Repeat each weld until you can pass the required visual inspection, especially for the 2G, 3G, and 4G positions required for the GTA welding SENSE qualification test in Chapter 23. Cut out the strips and free root bend them to check for 100% root penetration. Turn off the welding machine, shielding gas, and cooling water, and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 19-2

Lap and Tee Joints, All Positions Using Mild Steel with 100% Root Penetration to be Tested

For this practice, you will need a properly set-up and adjusted GTA welding machine, proper safety protection including all required PPE, ER70S-X filler rods 36 in. (0.9 m) long and ranging from 1/16 in. (2 mm) to 1/8 in. (3 mm) in diameter, two or more pieces of mild steel 6 in. (152 mm) long and ranging in thickness from 11 ga to 14 ga, 100% argon shielding gas, tungsten electrodes ranging from 1/16 in. (2 mm) to 1/8 in. (3 mm) in diameter, saw or thermal cutting torch, and a bench vise and ball-peen hammer, **Figure 19-7** and **Figure 19-8**.

Repeat each weld until you can pass the required visual inspection, especially for the 2F, 3F, and 4F positions required for the GTA welding SENSE qualification test in Chapter 23. Cut out the strips and free root bend them to check for 100% root penetration. Turn off the welding machine, shielding gas, and cooling water, and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

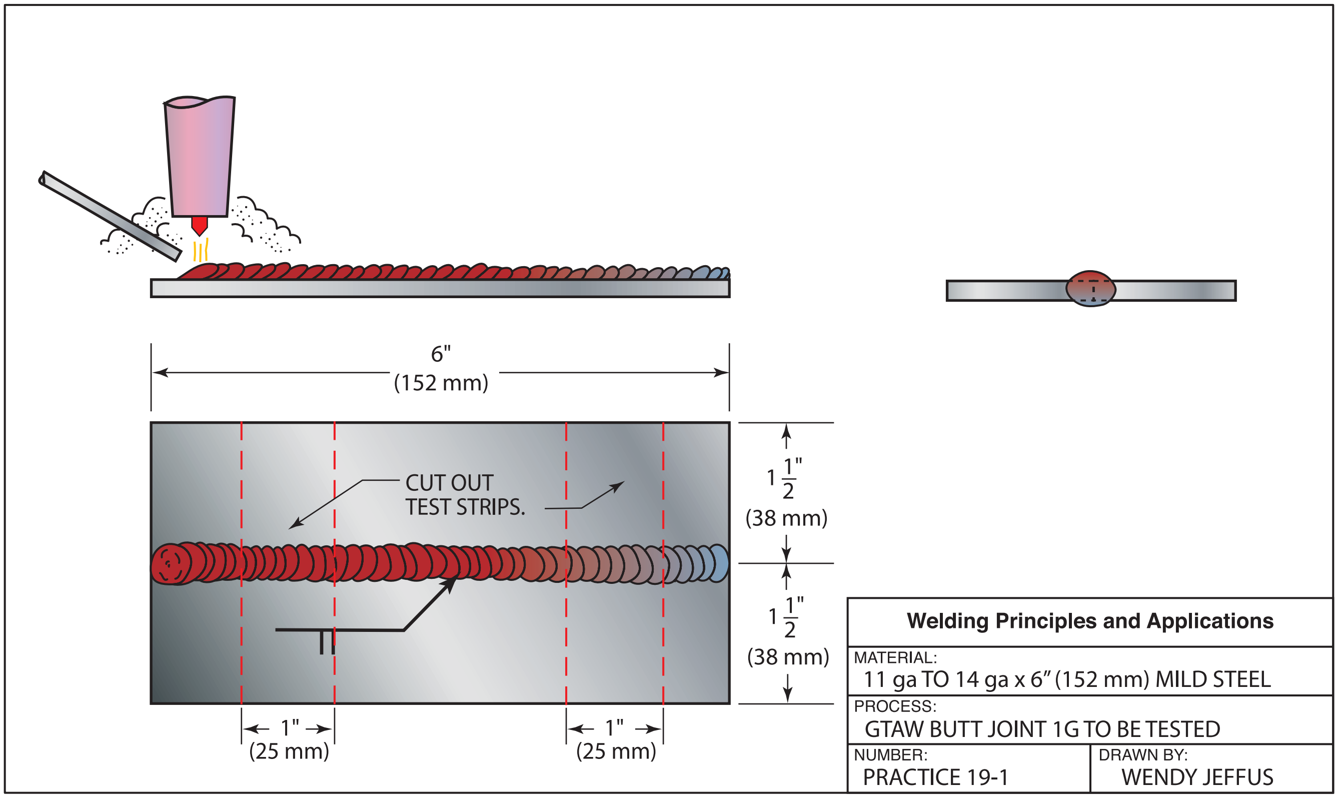


FIGURE 19-6 Butt joint in the flat position to be tested.

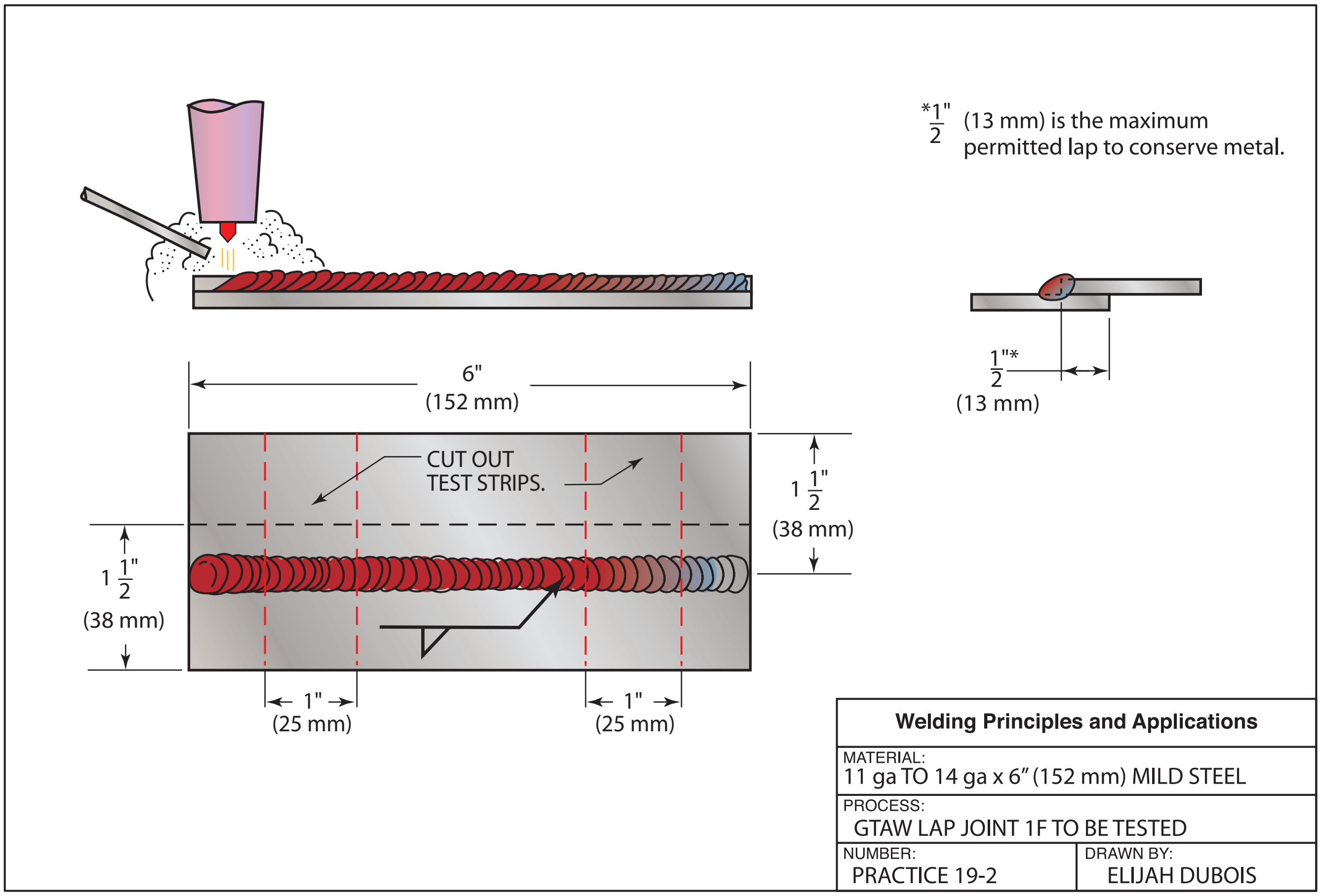


FIGURE 19-7 Lap joint in the flat position to be tested.

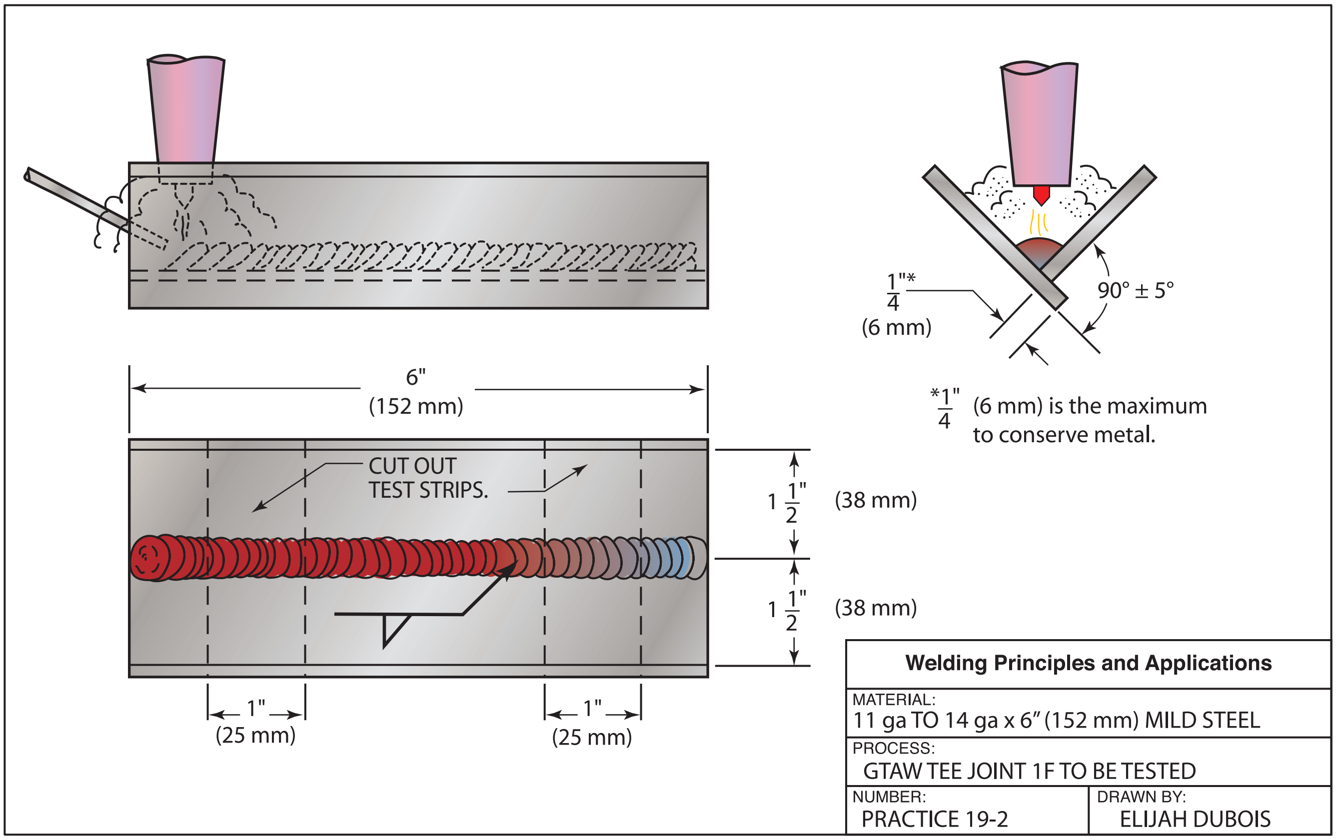


FIGURE 19-8 Tee joint in the flat position to be tested.

PRACTICE 19-3

Butt Joint, All Positions Using Austenitic Stainless Steel with 100% Joint Penetration to be Tested

For this practice, you will need a properly set-up and adjusted GTA welding machine, proper safety protection including all required PPE, ER3XX (stainless steel) filler rods 36 in. (0.9 m) long ranging from 1/16 in. (2 mm) to 1/8 in. (3 mm) in diameter, two or more pieces of austenitic stainless steel 6 in. (152 mm) long and ranging in thickness from 11 ga to 14 ga (mild steel can be used in place of stainless steel as long as stainless steel filler metal is used), 100% argon shielding gas, tungsten electrodes ranging from 1/16 in. (2 mm) to 1/8 in. (3 mm) in diameter, saw or PAC torch, and a bench vise and ball-peen hammer, Figure 19-6.

Repeat each weld until you can pass the required visual inspection, especially for the 1G and 2G positions required for the GTA welding SENSE qualification test in Chapter 23. Cut out the strips and free root bend them to check for 100% root penetration. Turn off the welding machine, shielding gas, and cooling water, and clean your work area when you are finished welding.

Complete a copy of the “Student Welding Report” listed in Appendix I or provided by your instructor. ◆

PRACTICE 19-4

Lap and Tee Joints, All Positions Using Stainless Steel with 100% Root Penetration to be Tested

For this practice, you will need a properly set-up and adjusted GTA welding machine, proper safety protection including all required PPE, ER3XX (stainless steel) filler rods 36 in. (0.9 m) long and ranging from 1/16 in. (2 mm) to 1/8 in. (3 mm) in diameter, two or more pieces of austenitic stainless steel 6 in. (152 mm) long and ranging in thickness from 11 ga to 14 ga (mild steel can be used in place of stainless steel as long as stainless steel filler metal is used), 100% argon shielding gas, tungsten electrodes ranging from 1/16 in. (2 mm) to 1/8 in. (3 mm) in diameter, saw or PAC torch, and a bench vise and ball-peen hammer, Figure 19-7 and Figure 19-8.

Repeat each weld until you can pass the required visual inspection, especially for the 2F and 3F positions required for the GTA welding SENSE qualification test in Chapter 23. Cut out the strips and free root bend them to check for 100% root penetration. Turn off the welding machine, shielding gas, and cooling water, and clean your work area when you are finished welding.

Complete a copy of the “Student Welding Report” listed in Appendix I or provided by your instructor. ◆

PRACTICE 19-5

Butt Joint, All Positions Using Aluminum with 100% Joint Penetration to Be Tested

For this practice, you will need a properly set-up and adjusted GTA welding machine, proper safety protection including all required PPE, ER4043 filler rods 36 in. (0.9 m) long, ranging from 1/16 in. (2 mm) to 1/8 in. (3 mm) in diameter, two or more pieces of mild steel 6 in. (152 mm) long and ranging in thickness from 11 ga to 14 ga, 100% argon shielding gas, tungsten electrodes ranging from 1/16 in. (2 mm) to 1/8 in. (3 mm) in diameter, saw or PAC torch, and a bench vise and ball-peen hammer, Figure 19-6.

Repeat each weld until you can pass the required visual inspection, especially for the 1G position required for the GTA welding SENSE qualification test in Chapter 23. Cut out the strips and free root bend them to check for 100% root penetration. Turn off the welding machine, shielding gas, and cooling water, and clean your work area when you are finished welding.

Complete a copy of the “Student Welding Report” listed in Appendix I or provided by your instructor. ◆

PRACTICE 19-6

Lap and Tee Joints, All Positions Using Aluminum with 100% Root Penetration to Be Tested

For this practice, you will need a properly set-up and adjusted GTA welding machine, proper safety protection including all required PPE, ER4043 filler rods 36 in. (0.9 m) long and ranging from 1/16 in. (2 mm) to 1/8 in. (3 mm) in diameter, two or more pieces of mild steel, 6 in. (152 mm) long and ranging in thickness from 11 ga to 14 ga, 100% argon shielding gas, tungsten electrodes ranging from 1/16 in. (2 mm) to 1/8 in. (3 mm) in diameter, saw or PAC torch, and a bench vise and ball-peen hammer, Figure 19-7 and Figure 19-8.

Repeat each weld until you can pass the required visual inspection. Cut out the strips and free root bend them to check for 100% root penetration. Turn off the welding machine, shielding gas, and cooling water, and clean your work area when you are finished welding.

Complete a copy of the “Student Welding Report” listed in Appendix I or provided by your instructor. ◆

PRACTICE 19-7 AWS SENSE

Gas Tungsten Arc Welding (GTAW) on Plain Carbon Steel Workmanship Sample

Welding Procedure Specification (WPS) No.: Practice 19-7.

Title:

Welding GTAW of sheet to sheet.

Scope:

This procedure is applicable for square groove and fillet welds within the range of 18 gauge through 10 gauge.

Welding may be performed in the following positions:

1G and 2F.

Base Metal:

The base metal shall conform to carbon steel M-1, Group 1.

Backing Material Specification:

None.

Filler Metal:

The filler metal shall conform to AWS specification no. #70S-3 for 1/16 in. (1.6 mm) to 3/32 in. (2.4 mm) diameter as listed in AWS specification A5.18. This filler metal falls into F-number F-6 and A-number A-1.

Electrode:

The tungsten electrode shall conform to AWS specification no. EWTh-2, EWCe-2, or EWLa from AWS specification A5.12. The tungsten diameter shall be 1/8 in. (3.2 mm) maximum.
The tungsten end shape shall be tapered at two to three times its length to its diameter.

Shielding Gas:

The shielding gas, or gases, shall conform to the following compositions and purity: welding grade argon.

Joint Design and Tolerances:

Refer to the drawing and specifications in **Figure 19-9** for the workmanship sample layout.

Preparation of Base Metal:

All hydrocarbons and other contaminants, such as cutting fluids, grease, oil, and primers, must be cleaned off all parts and filler metals before welding. This cleaning can be done with any suitable solvents or detergents. The joint face and inside and outside plate surface within 1 in. (25 mm) of the joint must be mechanically cleaned of slag, rust, and mill scale. Cleaning must be done with a wire brush or grinder down to bright metal.

Electrical Characteristics:

Set the welding current to DCEN and the amperage and shielding gas flow according to **Table 19-1**.

Preheat:

The parts must be heated to a temperature higher than 50°F (10°C) before any welding is started.

Backing Gas:

None.

Safety:

Proper protective clothing and equipment must be used. The area must be free of all hazards that may affect the welder or others in the area. The welding machine, welding leads, work clamp, electrode holder, and other equipment must be in safe working order.

Welding Technique:

TACK WELDS: With the parts securely clamped in place with the correct root gap, the tack welds are to be performed. Holding the electrode so that it is very close to the root face but not touching, slowly increase the current until the arc starts and a molten weld pool is formed. Add filler metal as required to maintain a slightly convex weld face and a flat or slightly concave root face. When it is time to end the tack weld, lower the current slowly so that the molten

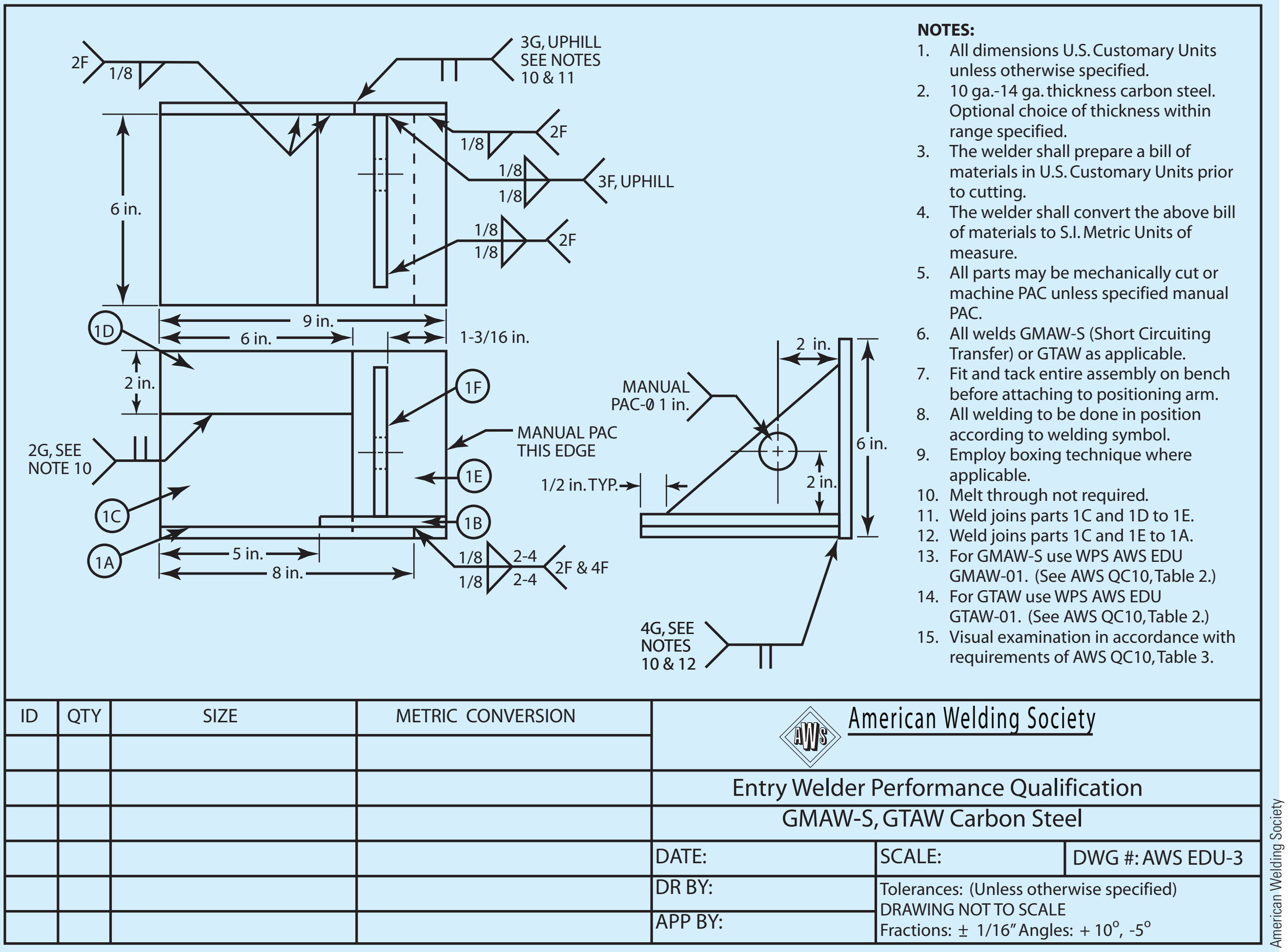


FIGURE 19-9 Practice 19-7 AWS SENSE plain carbon steel workmanship sample.

Metal Specifications		Gas Flow			Nozzle Size in. (mm)	Amperage Min. to Max.
Thickness	Diameter of E70S-3*	Rates cfm (L/min)	Preflow Times	Postflow Times		
18 ga	1/16 in. (2 mm)	15 to 20 (7 to 9)	10 to 15 sec	10 to 25 sec	1/4 to 3/8 (6 to 10)	45 to 65
17 ga	1/16 in. (2 mm)	15 to 20 (7 to 9)	10 to 15 sec	10 to 25 sec	1/4 to 3/8 (6 to 10)	45 to 70
16 ga	1/16 in. (2 mm)	15 to 20 (7 to 9)	10 to 15 sec	10 to 25 sec	1/4 to 3/8 (6 to 10)	50 to 75
15 ga	1/16 in. (2 mm)	15 to 20 (7 to 9)	10 to 15 sec	10 to 25 sec	1/4 to 3/8 (6 to 10)	55 to 80
14 ga	3.32 in. (2.4 mm)	20 to 25 (9 to 12)	10 to 20 sec	10 to 30 sec	3/8 to 5/8 (10 to 16)	60 to 90
13 ga	3.32 in. (2.4 mm)	20 to 25 (9 to 12)	10 to 20 sec	10 to 30 sec	3/8 to 5/8 (10 to 16)	60 to 100
12 ga	3.32 in. (2.4 mm)	20 to 25 (9 to 12)	10 to 20 sec	10 to 30 sec	3/8 to 5/8 (10 to 16)	60 to 110
11 ga	3.32 in. (2.4 mm)	20 to 25 (9 to 12)	10 to 20 sec	10 to 30 sec	3/8 to 5/8 (10 to 16)	65 to 120
10 ga	3.32 in. (2.4 mm)	20 to 25 (9 to 12)	10 to 20 sec	10 to 30 sec	3/8 to 5/8 (10 to 16)	70 to 130

*Other E70S-X filler metal may be used.

TABLE 19-1 Welding Setup for Mild Steel GTA Welds

weld pool can be tapered down in size. When all tack welds are complete, allow the parts to cool as needed before assembling the remaining parts. Repeat the tack welding procedure until the entire part is assembled.

SQUARE GROOVE AND FILLET WELDS: Holding the electrode so that it is very close to the metal surface but not touching, slowly increase the current until the arc starts and a molten weld pool is formed. As the weld progresses, add filler metal as required to maintain a flat or slightly convex weld face. If it is necessary to stop the weld or to reposition yourself or if the weld is completed, the current must be lowered slowly so that the molten weld pool can be tapered down in size.

Interpass Temperature:

The plate should not be heated to a temperature higher than 120°F (49°C) during the welding process. After each weld pass is completed, allow it to cool, but never to a temperature below 50°F (10°C). The weldment must not be quenched in water.

Cleaning:

Recleaning may be required if the parts or filler metal becomes contaminated or reoxidized to a degree that the weld quality will be affected. Reclean using the same procedure used for the original metal preparation.

Visual Inspection:

Visual inspection criteria for entry welders:

1. There shall be no cracks and no incomplete fusion.
2. There shall be no incomplete joint penetration in groove welds except as permitted for partial joint penetration groove welds.
3. The Test Supervisor shall examine the weld for acceptable appearance and shall be satisfied that the welder is skilled in using the process and procedure specified for the test.
4. Undercut shall not exceed the lesser of 10% of the base metal thickness or 1/32 in. (0.8 mm).
5. Where visual examination is the only criterion for acceptance, all weld passes are subject to visual examination at the discretion of the Test Supervisor.
6. The frequency of porosity shall not exceed one in each 4 in. (100 mm) of weld length, and the maximum diameter shall not exceed 3/32 in. (2.4 mm).
7. Welds shall be free from overlap.

Sketches:

Gas Tungsten Arc Welding (GTAW) Workmanship Sample drawing for Carbon Steel, **Figure 19-10.**

Paperwork:

Complete a "Bill of Materials," "Time Sheet," and "Performance Qualification Test Record" in Appendix I or as provided by your instructor. ◆

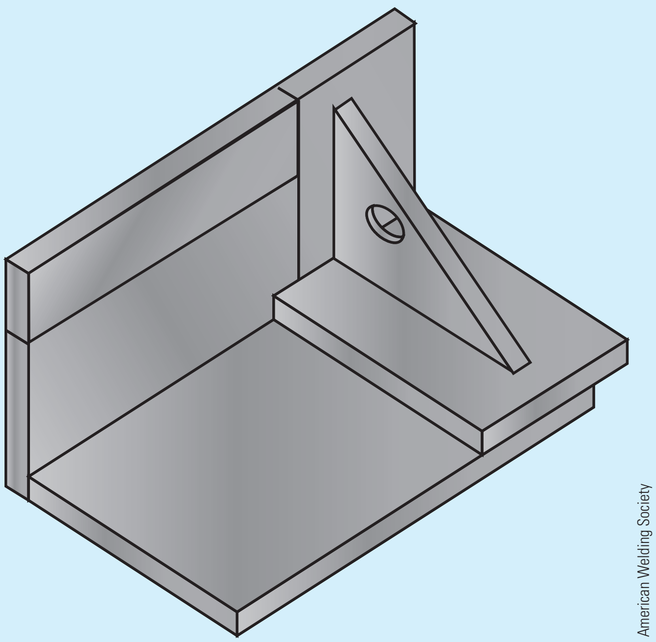


FIGURE 19-10 Carbon steel workmanship sample.

PRACTICE 19-8 AWS SENSE

Gas Tungsten Arc Welding (GTAW) on Stainless Steel Workmanship Sample

Welding Procedure Specification (WPS) No.: Practice 19-8.

Title:

Welding GTAW of sheet to sheet.

Scope:

This procedure is applicable for square groove and fillet welds within the range of 18 gauge through 10 gauge.

Welding may be performed in the following positions:

1G and 2F.

Base Metal:

The base metal shall conform to austenitic stainless steel M-8 or P-8.

Backing Material Specification:

None.

Filler Metal:

The filler metal shall conform to AWS specification no. ER3XX from AWS specification A5.9. This filler metal falls into F-number F-6 and A-number A-8.

Electrode:

The tungsten electrode shall conform to AWS specification no. EWTh-2, EWCe-2, or EWLa from AWS specification A5.12. The tungsten diameter shall be 1/8 in. (3.2 mm) maximum. The tungsten end shape shall be tapered at two to three times its length to its diameter.

Shielding Gas:

The shielding gas, or gases, shall conform to the following compositions and purity: welding grade argon.

Joint Design and Tolerances:

Refer to the drawing and specifications in **Figure 19-11** for the workmanship sample layout.

Preparation of Base Metal:

All hydrocarbons and other contaminants, such as cutting fluids, grease, oil, and primers, must be cleaned off all parts and filler metals before welding. This cleaning can be done with any suitable solvents or detergents. The joint face and inside and outside plate surface within 1 in. (25 mm) of the joint must be cleaned of slag, oxide, and scale. Cleaning can be mechanical or chemical. Mechanical metal cleaning can be done by grinding, stainless steel wire brushing, scraping, machining, or filing. Chemical cleaning can be done by using acids, alkalis, solvents, or detergents. Cleaning must be done down to bright metal.

Electrical Characteristics:

Set the welding current to DCEN and the amperage and shielding gas flow according to **Table 19-2**.

Preheat:

The parts must be heated to a temperature higher than 50°F (10°C) before any welding is started.

Backing Gas:

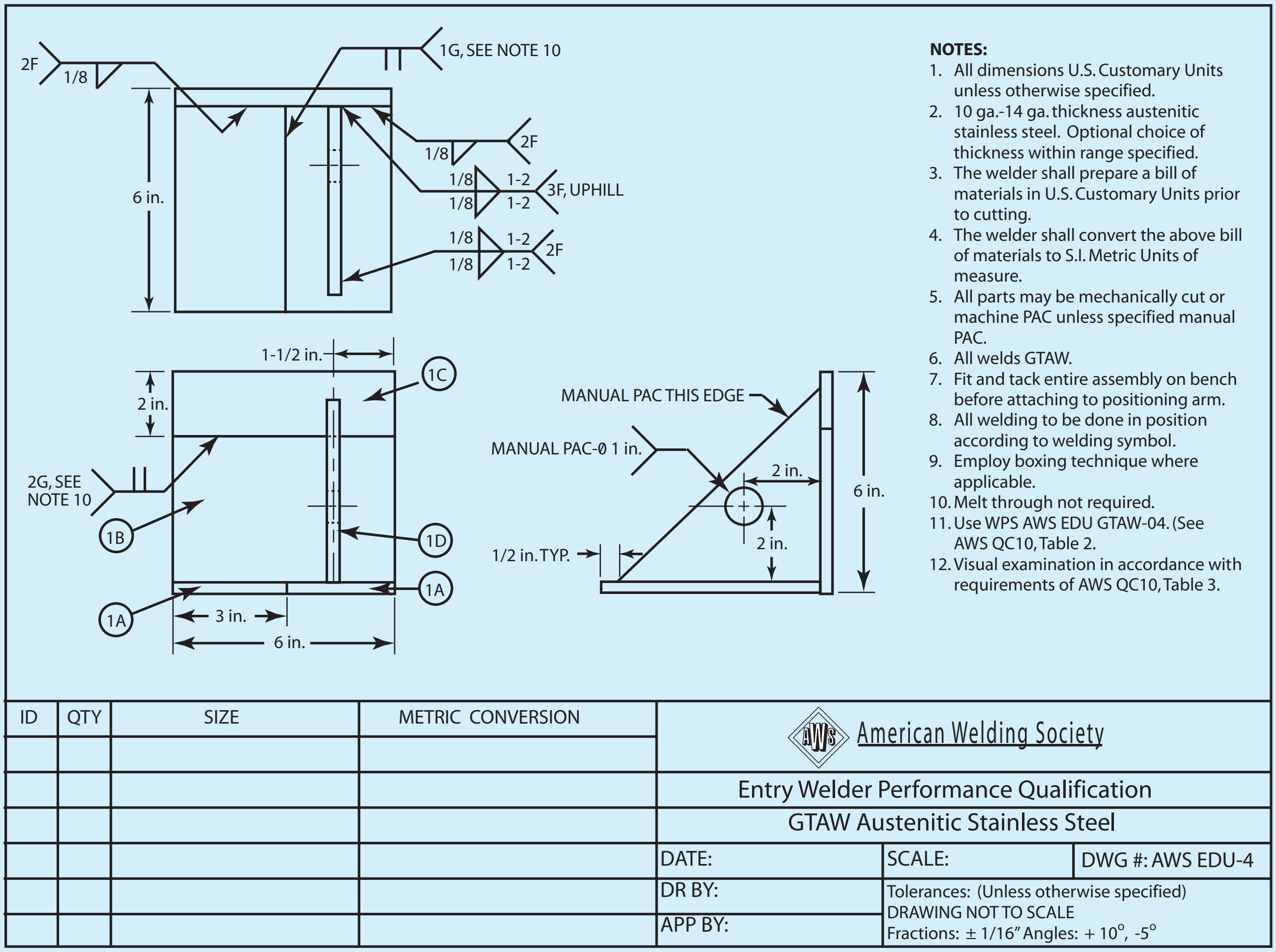
None.

Safety:

Proper protective clothing and equipment must be used. The area must be free of all hazards that may affect the welder or others in the area. The welding machine, welding leads, work clamp, electrode holder, and other equipment must be in safe working order.

Welding Technique:

TACK WELDS: With the parts securely clamped in place with the correct root gap, the tack welds are to be performed. Holding the electrode so that it is very close to the root face but not touching, slowly increase the current



American Welding Society

FIGURE 19-11 Practice 19-8 AWS SENSE stainless steel workmanship sample.

Metal Specifications		Gas Flow			Nozzle Size in. (mm)	Amperage Min. to Max.
Thickness	Diameter of ER3XX* (in.)	Rates cfm (L/min)	Preflow Times	Postflow Times		
18 ga	1/16 in. (2 mm)	15 to 20 (7 to 9)	10 to 15 sec	10 to 25 sec	1/4 to 3/8 (6 to 10)	35 to 60
17 ga	1/16 in. (2 mm)	15 to 20 (7 to 9)	10 to 15 sec	10 to 25 sec	1/4 to 3/8 (6 to 10)	40 to 65
16 ga	1/16 in. (2 mm)	15 to 20 (7 to 9)	10 to 15 sec	10 to 25 sec	1/4 to 3/8 (6 to 10)	40 to 75
15 ga	1/16 in. (2 mm)	15 to 20 (7 to 9)	10 to 15 sec	10 to 25 sec	1/4 to 3/8 (6 to 10)	50 to 80
14 ga	3.32 in. (2.4 mm)	20 to 25 (9 to 12)	10 to 20 sec	10 to 30 sec	3/8 to 5/8 (10 to 16)	50 to 90
13 ga	3.32 in. (2.4 mm)	20 to 25 (9 to 12)	10 to 20 sec	10 to 30 sec	3/8 to 5/8 (10 to 16)	55 to 100
12 ga	3.32 in. (2.4 mm)	20 to 25 (9 to 12)	10 to 20 sec	10 to 30 sec	3/8 to 5/8 (10 to 16)	60 to 110
11 ga	3.32 in. (2.4 mm)	20 to 25 (9 to 12)	10 to 20 sec	10 to 30 sec	3/8 to 5/8 (10 to 16)	65 to 120
10 ga	3.32 in. (2.4 mm)	20 to 25 (9 to 12)	10 to 20 sec	10 to 30 sec	3/8 to 5/8 (10 to 16)	70 to 130

*Other ER3XX stainless steel A5.9 filler metal may be used.

TABLE 19-2 Welding Setup for Stainless Steel GTA Welds

until the arc starts and a molten weld pool is formed. Add filler metal as required to maintain a slightly convex weld face and a flat or slightly concave root face. When it is time to end the tack weld, lower the current slowly so that the molten weld pool can be tapered down in size. When all tack welds are complete, allow the parts to cool as needed before assembling the remaining parts. Repeat the tack welding procedure until the entire part is assembled.

SQUARE GROOVE AND FILLET WELDS: Holding the electrode so that it is very close to the metal surface but not touching, slowly increase the current until the arc starts and a molten weld pool is formed. As the weld progresses, add filler metal as required to maintain a flat or slightly convex weld face. If it is necessary to stop the weld or to reposition yourself or if the weld is completed, then the current must be lowered slowly so that the molten weld pool can be tapered down in size.

Interpass Temperature:

The plate should not be heated to a temperature higher than 350°F (180°C) during the welding process. After each weld pass is completed, allow it to cool, but never to a temperature below 50°F (10°C). The weldment must not be quenched in water.

Cleaning:

Recleaning may be required if the parts or filler metal become contaminated or oxidized to a degree that the weld quality will be affected. Reclean using the same procedure used for the original metal preparation.

Visual Inspection:

Visual inspection criteria for entry welders:

1. There shall be no cracks and no incomplete fusion.
2. There shall be no incomplete joint penetration in groove welds except as permitted for partial joint penetration groove welds.
3. The Test Supervisor shall examine the weld for acceptable appearance and shall be satisfied that the welder is skilled in using the process and procedure specified for the test.
4. Undercut shall not exceed the lesser of 10% of the base metal thickness or 1/32 in. (0.8 mm).
5. Where visual examination is the only criterion for acceptance, all weld passes are subject to visual examination at the discretion of the Test Supervisor.
6. The frequency of porosity shall not exceed one in each 4 in. (100 mm) of weld length and the maximum diameter shall not exceed 3/32 in. (2.4 mm).
7. Welds shall be free from overlap.

Sketches:

Gas Tungsten Arc Welding (GTAW) Workmanship Sample drawing for Stainless Steel, **Figure 19-12**.

Paperwork:

Complete a "Bill of Materials," "Time Sheet," and "Performance Qualification Test Record" in Appendix I or as provided by your instructor. ◆

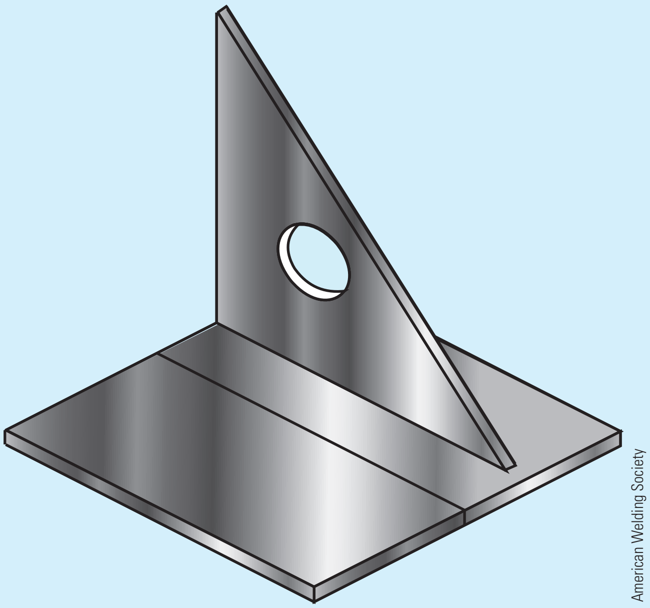


FIGURE 19-12 Stainless steel workmanship sample.

PRACTICE 19-9 AWS SENSE

Gas Tungsten Arc Welding (GTAW) on Aluminum Workmanship Sample

Welding Procedure Specification (WPS) No.: Practice 19-9.

Title:

Welding GTAW of sheet to sheet.

Scope:

This procedure is applicable for square groove and fillet welds within the range of 18 gauge through 10 gauge.

Welding may be performed in the following positions:

1G and 2F.

Base Metal:

The base metal shall conform to aluminum M-22 or P-22.

Backing Material Specification:

None.

Filler Metal:

The filler metal shall conform to AWS specification no. ER4043 from AWS specification A5.10. This filler metal falls into F-number F-22 and A-number A-5.10.

Electrode:

The tungsten electrode shall conform to AWS specification no. EWCe-2, EWZr, EWLa, or EWP from AWS specification A5.12. The tungsten diameter shall be 1/8 in. (3.2 mm) maximum. The tungsten end shape shall be rounded.

Shielding Gas:

The shielding gas, or gases, shall conform to the following compositions and purity: welding grade argon.

Joint Design and Tolerances:

Refer to the drawing and specifications in **Figure 19-13** for the workmanship sample layout.

Preparation of Base Metal:

All hydrocarbons and other contaminants, such as cutting fluids, grease, oil, and primers, must be cleaned off all parts and filler metals before welding. This cleaning can be done with any suitable solvents or detergents. The joint face and inside and outside plate surface within 1 in. (25 mm) of the joint must be mechanically or chemically cleaned of oxides. Mechanical cleaning may be done by stainless steel wire brushing, scraping, machining, or filing. Chemical cleaning may be done by using acids, alkalis, solvents, or detergents. Because the oxide layer may reform quickly and affect the weld, welding should be started within 10 minutes of cleaning.

Electrical Characteristics:

Set the welding current to AC high-frequency stabilized and the amperage and shielding gas flow according to **Table 19-3.**

Preheat:

The parts must be heated to a temperature higher than 50°F (10°C) before any welding is started.

Backing Gas:

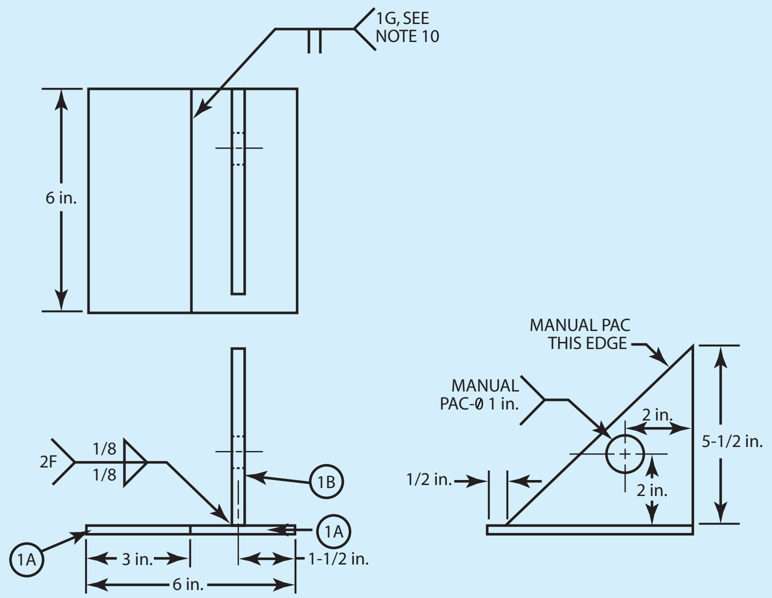
N/A.

Safety:

Proper protective clothing and equipment must be used. The area must be free of all hazards that may affect the welder or others in the area. The welding machine, welding leads, work clamp, electrode holder, and other equipment must be in safe working order.

Welding Technique:

The welder’s hands or gloves must be clean and oil-free to prevent contamination of the metal or filler rods.



NOTES:
1. All dimensions U.S. Customary Units unless otherwise specified.
2. 10 ga.-14 ga. thickness aluminum. Optional choice of thickness within range specified.
3. The welder shall prepare a bill of materials in U.S. Customary Units prior to cutting.
4. The welder shall convert the above bill of materials to S.I. Metric Units of measure.
5. All parts may be mechanically cut or machine PAC unless specified manual PAC.
6. All welds GTAW.
7. Fit and tack entire assembly on bench before attaching to positioning arm.
8. All welding to be done in position according to welding symbol.
9. Employ boxing technique where applicable.
10. Melt through not required.
11. Use WPS AWS EDU GTAW-03 for 4000/5000 Series aluminum. (See AWS QC10, Table 2.)
12. Visual examination in accordance with requirements of AWS QC10, Table 3.

ID	QTY	SIZE	METRIC CONVERSION

American Welding Society

Entry Welder Performance Qualification

GTAW Aluminum

DATE:	SCALE:	DWG #: AWS EDU-5
DR BY:	Tolerances: (Unless otherwise specified) DRAWING NOT TO SCALE Fractions: ± 1/16" Angles: + 10°, -5°	
APP BY:		

American Welding Society

FIGURE 19-13 Practice 19-9 AWS SENSE aluminum workmanship sample.

Metal Specifications		Gas Flow			Nozzle Size in. (mm)	Amperage Min. to Max.
Thickness	Diameter of ER4043*	Rates cfm (L/min)	Preflow Times	Postflow Times		
18 ga	3/32 in. (2.4 mm)	20 to 30 (9 to 14)	10 to 15 sec	10 to 25 sec	1/4 to 3/8 (6 to 10)	40 to 60
17 ga	3/32 in. (2.4 mm)	20 to 30 (9 to 14)	10 to 15 sec	10 to 25 sec	1/4 to 3/8 (6 to 10)	50 to 70
16 ga	3/32 in. (2.4 mm)	20 to 30 (9 to 14)	10 to 15 sec	10 to 25 sec	1/4 to 3/8 (6 to 10)	60 to 75
15 ga	3/32 in. (2.4 mm)	20 to 30 (9 to 14)	10 to 15 sec	10 to 25 sec	1/4 to 3/8 (6 to 10)	65 to 85
14 ga	3/32 in. (2.4 mm)	20 to 30 (9 to 14)	10 to 15 sec	10 to 25 sec	1/4 to 3/8 (6 to 10)	75 to 90
13 ga	1/8 in. (3 mm)	25 to 40 (12 to 19)	10 to 20 sec	10 to 30 sec	3/8 to 5/8 (10 to 16)	85 to 100
12 ga	1/8 in. (3 mm)	25 to 40 (12 to 19)	10 to 20 sec	10 to 30 sec	3/8 to 5/8 (10 to 16)	90 to 110
11 ga	1/8 in. (3 mm)	25 to 40 (12 to 19)	10 to 20 sec	10 to 30 sec	3/8 to 5/8 (10 to 16)	100 to 115
10 ga	1/8 in. (3 mm)	25 to 40 (12 to 19)	10 to 20 sec	10 to 30 sec	3/8 to 5/8 (10 to 16)	100 to 125

*Other aluminum AWS A5.10 filler metal may be used if needed.

TABLE 19-3 Welding Setup for Aluminum GTA Welds

TACK WELDS: With the parts securely clamped in place with the correct root gap, the tack welds are to be performed. Holding the electrode so that it is very close to the root face but not touching, slowly increase the current until the arc starts and a molten weld pool is formed. Add filler metal as required to maintain a slightly convex weld face and a flat or slightly concave root face. When it is time to end the tack weld, lower the current slowly so that the molten weld pool can be tapered down in size. When all tack welds are complete, allow the parts to cool as needed before assembling the remaining parts. Repeat the tack welding procedure until the entire part is assembled.

SQUARE GROOVE AND FILLET WELDS: Holding the electrode so that it is very close to the metal surface but not touching, slowly increase the current until the arc starts and a molten weld pool is formed. As the weld progresses, add filler metal as required to maintain a flat or slightly convex weld face. If it is necessary to stop the weld or to reposition yourself or the weld is completed, then the current must be lowered slowly so that the molten weld pool can be tapered down in size.

Interpass Temperature:

The plate should not be heated to a temperature higher than 120°F (49°C) during the welding process. After each weld pass is completed, allow it to cool, but never to a temperature below 50°F (10°C). The weldment must not be quenched in water.

Cleaning:

Recleaning may be required if the parts or filler metal become contaminated or oxidized to a degree that the weld quality will be affected. Reclean using the same procedure used for the original metal preparation.

Visual Inspection:

Visual inspection criteria for entry welders:

1. There shall be no cracks and no incomplete fusion.
2. There shall be no incomplete joint penetration in groove welds except as permitted for partial joint penetration groove welds.
3. The Test Supervisor shall examine the weld for acceptable appearance and shall be satisfied that the welder is skilled in using the process and procedure specified for the test.
4. Undercut shall not exceed the lesser of 10% of the base metal thickness or 1/32 in. (0.8 mm).
5. When visual examination is the only criterion for acceptance, all weld passes are subject to visual examination at the discretion of the Test Supervisor.
6. The frequency of porosity shall not exceed one in each 4 in. (100 mm) of weld length, and the maximum diameter shall not exceed 3/32 in. (2.4 mm).
7. Welds shall be free from overlap.

Sketches:

Gas Tungsten Arc Welding (GTAW) Workmanship Sample drawing for Aluminum, **Figure 19-14.**

Paperwork:

Complete a "Bill of Materials," "Time Sheet," and "Performance Qualification Test Record" in Appendix I or as provided by your instructor. ◆

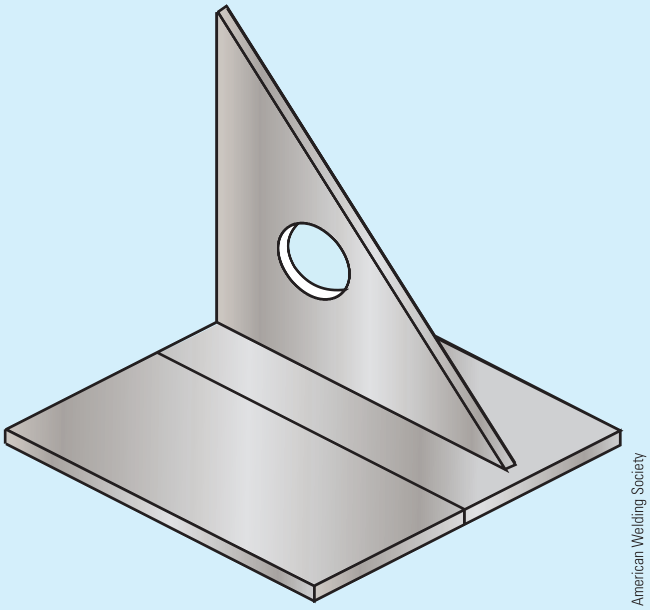


FIGURE 19-14 Aluminum workmanship sample.

TUBING AND PIPE PRACTICE WELDS

PRACTICE 19-10 AWS SENSE

2G and 5G Pipe Welds on Mild Steel Tubing with and without a Backing

For this AWS SENSE Level II GTA welding workmanship qualification practice, you will need a properly set-up and adjusted GTA welding machine, proper safety protection including all required PPE, ER70S-X filler rods 36 in. (0.9 m) long and ranging from 1/16 in. (2 mm) to 1/8 in. (3 mm) in diameter, two or more pieces of 1 in. to 2 7/8 in. (25 mm to 70 mm) diameter mild steel tubing 3 in. (74 mm) long and ranging in thickness from 10 ga to 18 ga, 100% argon shielding gas, and tungsten electrodes ranging from 1/16 in. (2 mm) to 1/8 in. (3 mm) in diameter.

Follow all of the instructions and joint configuration on the Workmanship Qualification drawing, **Figure 19-15**.

THINK GREEN

If you determine that a weld does not pass your visual inspection, you can conserve materials by sawing or cutting off the weld so the ends of the tubing can be reused.

Repeat each weld until you can pass the required visual inspection. Turn off the welding machine, shielding gas, and cooling water, and clean your work area when you are finished welding.

Complete a copy of the "Student SENSE Welding Report" listed in Appendix X or provided by your instructor. ◆

PRACTICE 19-11 AWS SENSE

2G and 5G Pipe Welds on Stainless Steel Tubing with and without a Backing

For this AWS SENSE Level II GTA welding workmanship qualification practice, you will need a properly set-up and adjusted GTA welding machine, proper safety protection including all required PPE, ER3XX (stainless steel) filler rods 36 in. (0.9 m) long and ranging from 1/16 in. (2 mm) to 1/8 in. (3 mm) in diameter, two or more pieces of 1 in. to 2 7/8 in. (25 mm to 70 mm) diameter stainless steel tubing 3 in. (74 mm) long and ranging in thickness from 10 ga to 18 ga, 100% argon shielding gas, and tungsten electrodes ranging from 1/16 in. (2 mm) to 1/8 in. (3 mm) in diameter.

Follow all of the instructions and joint configuration on the Workmanship Qualification drawing, **Figure 19-16**.

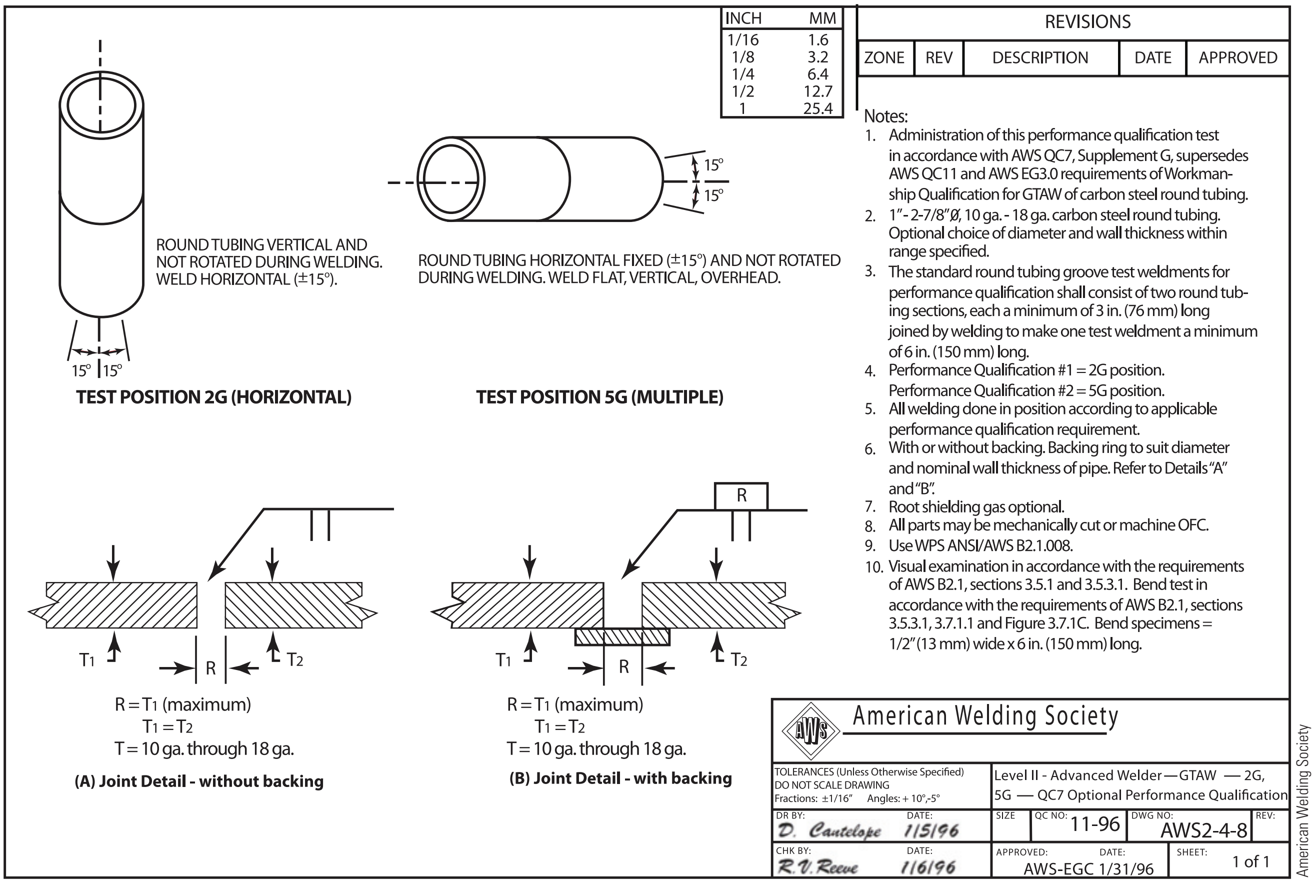


FIGURE 19-15 Practice 19-10 AWS SENSE mild steel tubing workmanship sample.

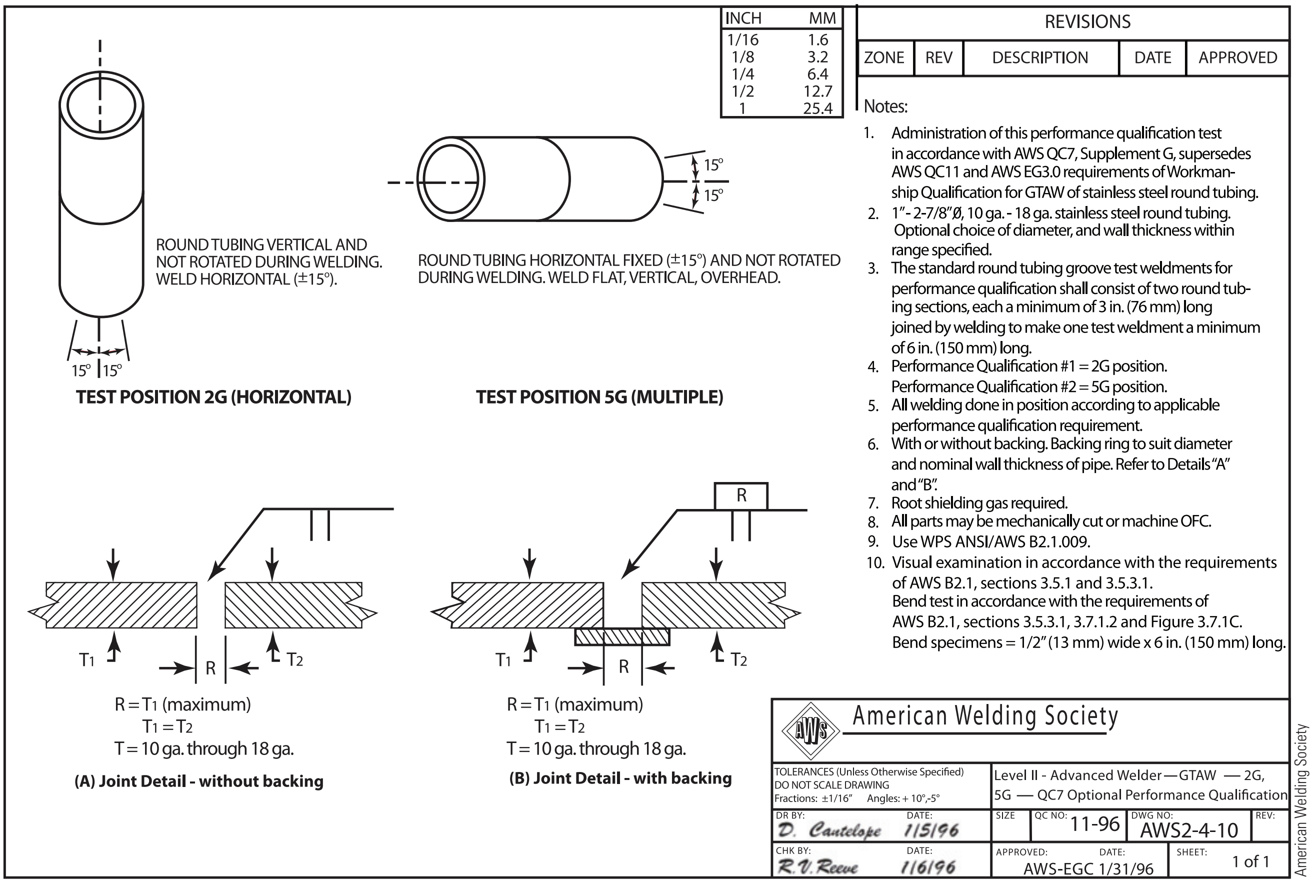


FIGURE 19-16 Practice 19-11 AWS SENSE stainless steel tubing workmanship sample.

Repeat each weld until you can pass the required visual inspection. Turn off the welding machine, shielding gas, and cooling water, and clean your work area when you are finished welding.

Complete a copy of the "Student SENSE Welding Report" listed in Appendix X or provided by your instructor. ◆

Repeat each weld until you can pass the required visual inspection. Turn off the welding machine, shielding gas, and cooling water, and clean your work area when you are finished welding.

Complete a copy of the "Student SENSE Welding Report" listed in Appendix X or provided by your instructor. ◆

PRACTICE 19-12 AWS SENSE

2G and 5G Pipe Welds on Aluminum Tubing with and without a Backing

For this AWS SENSE Level II GTA welding workmanship qualification practice, you will need a properly set-up and adjusted GTA welding machine, proper safety protection including all required PPE, ER4042 or ER5XXX (aluminum) filler rods 36 in. (0.9 m) long and ranging from 1/16 in. (2 mm) to 1/8 in. (3 mm) in diameter, two or more pieces of 1-in. to 2 7/8-in. (25 mm to 70 mm) diameter aluminum tubing 3 in. (74 mm) long and ranging in thickness from 10 ga to 18 ga, 100% argon shielding gas, and tungsten electrodes ranging from 1/16 in. (2 mm) to 1/8 in. (3 mm) in diameter.

Follow all of the instructions and joint configuration on the Workmanship Qualification drawing, **Figure 19-17**.

PRACTICE 19-13

Single V-Groove Pipe Weld, 1G Position, to be Tested

Using a properly set-up and adjusted GTA welding machine, proper safety protection, two or more pieces of 3-in. (76-mm) to 10-in. (254-mm) diameter schedule 40 mild steel pipe prepared with a single bevel on one end, and a few filler rods with 1/16-in. (2-mm), 3/32-in. (2.4-mm), and 1/8-in. (3-mm) diameters, you will make a V-groove weld with 100% root penetration, **Figure 19-18**.

Clean the inside and outside surfaces at least 1 in. (25 mm) on both sides of the groove. Tack weld the pipe together in four places with a 1- to 1 1/2-in. (25 to 37 mm)-long weld. Use a grinder with a narrow grinding disk and feather the tack welds, **Figure 19-19**. Make the root pass, filler pass, and cover pass as shown in **Figure 19-20**.

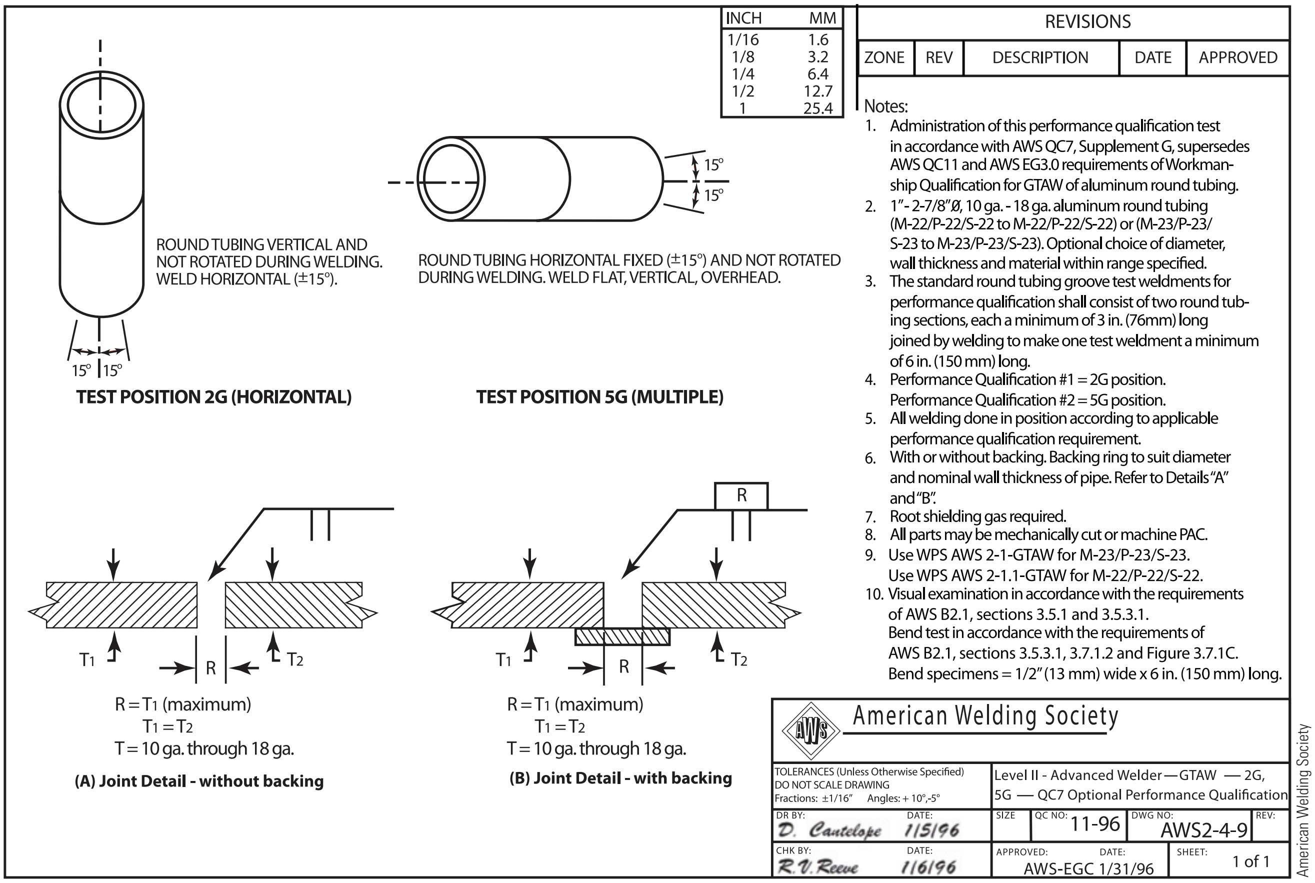


FIGURE 19-17 Practice 19-12 AWS SENSE aluminum tubing workmanship sample.

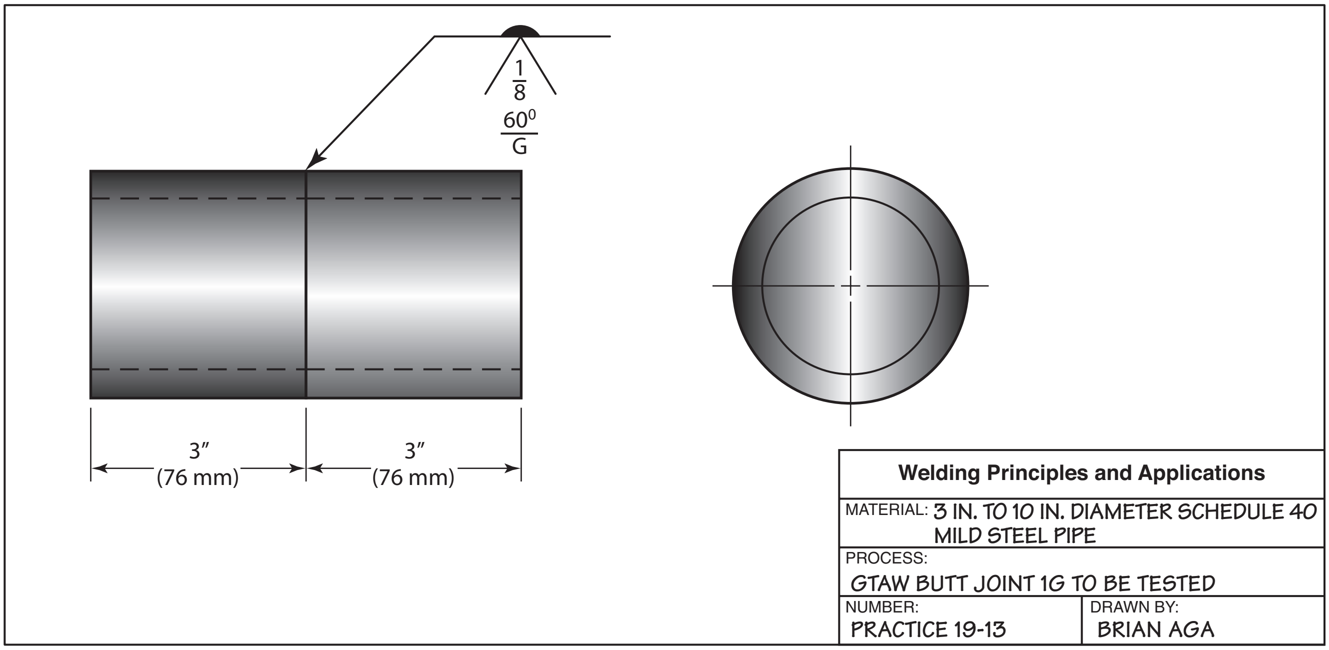


FIGURE 19-18 Practice 19-13 1G pipe weld to be tested.

When the weld is complete, inspect it for defects. If it passes visual inspection, cut out guided-bend test specimens as shown in **Figure 19-21**. It is important that the grinding marks on the test specimens are made so that they run in the direction of the bend, **Figure 19-22**. Test the specimens for weld defects. Repeat this practice until the test is passed. Turn off the welding machine, shielding gas, and cooling water, and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

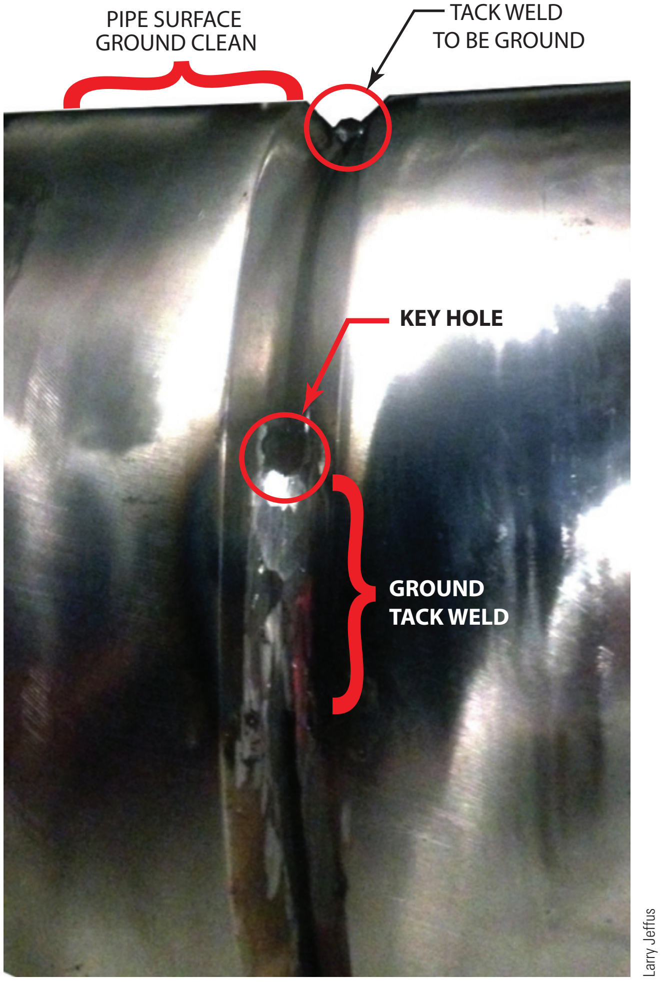


FIGURE 19-19 Proper pipe joint preparation and tack welding.

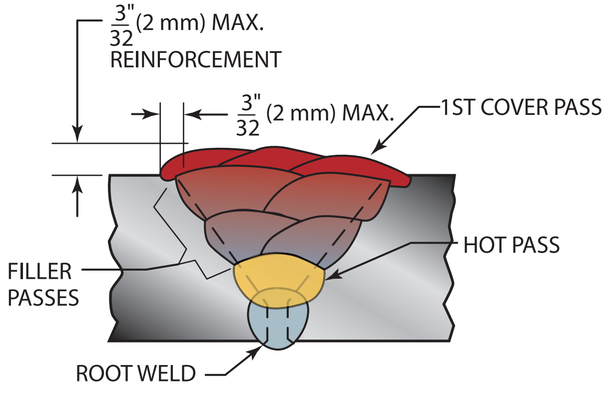


FIGURE 19-20 Weld bead sequence.

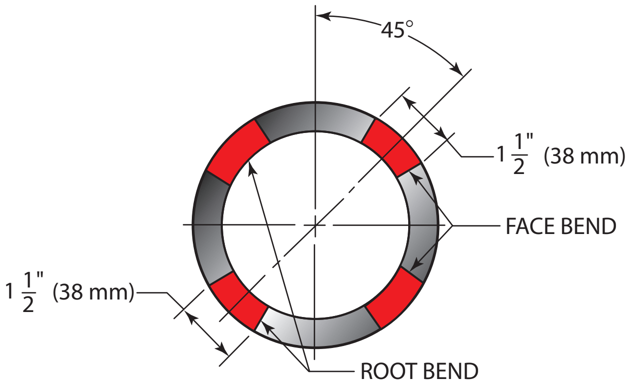


FIGURE 19-21 Weld test specimen locations.

FIGURE 19-22 The grinding marks on the test specimens must run in the direction of the bend.

PRACTICE 19-14

Single-V Butt Joint (5G Position) 100% Root Penetration to be Tested

Using the same equipment, setup, and materials as listed in Practice 19-13, make a weld on a pipe in the horizontal fixed (5G) position.

CAUTION

It is very important that the pipe is mounted so that it does not move or vibrate as it is being welded. Movement can increase the possibility that the tungsten will become contaminated. High-frequency vibration such as that caused by a compressor, fan, or other similar machine can cause the molten weld pool to become more fluid, making it difficult to control.

The pipes should be tack welded, and the tacks should be made in the following clock positions: 12 o'clock, 3 o'clock, 6 o'clock, and 9 o'clock, **Figure 19-23**.

- Start the root weld at the 6:30 o'clock position and weld uphill around one side of the pipe to the 12:30 o'clock position. Start with the cup against the pipe bevels as was done before, and add the rod at the leading edge of the molten weld pool.
- Repeat this process up the other side of the pipe. The starts and stops of these welds should overlap slightly to ensure a good tie-in.

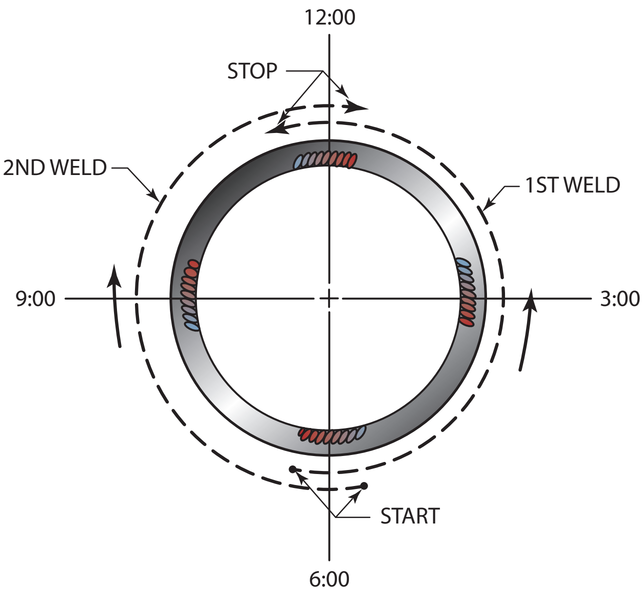


FIGURE 19-23 Proper starting and ending locations for 5G root pass.

The filler passes should also start near the 6:30 o'clock position and go up both sides of the pipe to a point near the 12:30 o'clock position, **Figure 19-24**. Staggering the location of these beads will help prevent defects arising from discontinuities caused at the starting and stopping points. Keeping these beads small will help you to control them. A large number of good weld beads are more desirable than a few poorly controlled beads.

The cover pass may be made as either a weave or a **lace bead**. The lace bead is usually more easily controlled because the molten weld pool is smaller.

- After the weld is complete, visually inspect it for uniformity in width and reinforcement.
- Check also for visible defects and root penetration.
- If the joint passes all visual tests and has 100% root penetration, then guided-bend test specimens can be cut out (refer to Figure 19-21).
- After bending, evaluate the specimens for defects. Repeat this practice until both parts A and B can be passed.

Turn off the welding machine, shielding gas, and cooling water, and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 19-15

Single-V Butt Joint (2G Position) 100% Root Penetration to be Tested

Using the same equipment, setup, and materials as listed in Practice 19-13, you will weld a butt joint on a pipe in the vertical fixed (2G) position.

Tack weld the pipes and start the root pass at a point between the tack welds. The root weld should be small enough so that surface tension will hold it in place. Too large of a root weld bead will cause the top root face to be slightly concave.

The filler passes can be larger if they are made along the lower beveled surface, **Figure 19-25**. This will support the filler passes and allow a faster joint buildup. The next pass is on the top side of the first. This process of resting the next pass on the last pass continues until the joint is filled.

The cover pass is started around the lower side of the joint, overlapping the pipe surface by no more than 1/8 in. (3 mm). The next pass covers approximately one-half of the first cover pass and should be slightly larger. This process of making each pass larger continues until the center weld is complete. Then, each weld is smaller than the last. This process builds a uniform reinforcement with a good profile.

After the weld is complete, visually inspect it for uniformity and defects. If it passes, inspect the root for 100% penetration. If the root passes, cut out guided-bend test specimens. Test the specimens and evaluate the results. Repeat this weld until both parts A and B can be passed. Turn off the welding machine, shielding gas, and cooling water, and clean your work area when you are finished welding.

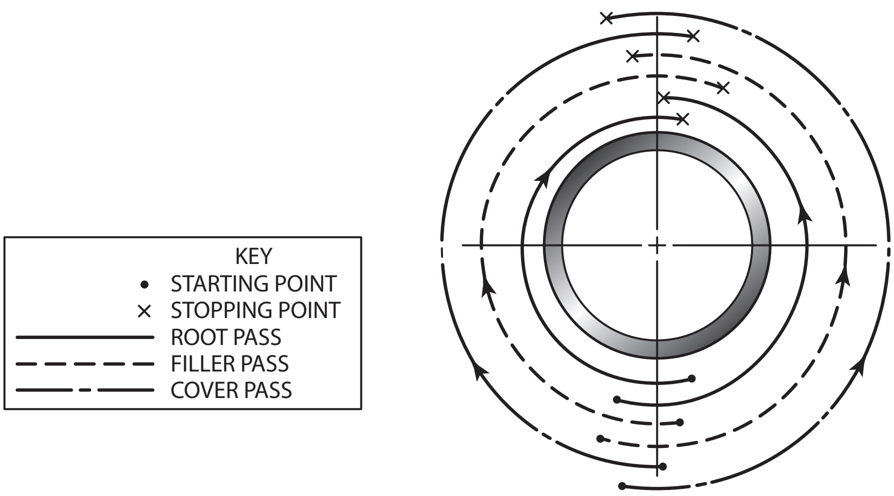


FIGURE 19-24 Proper starting and ending locations for 5G hot, filler, and cover passes.

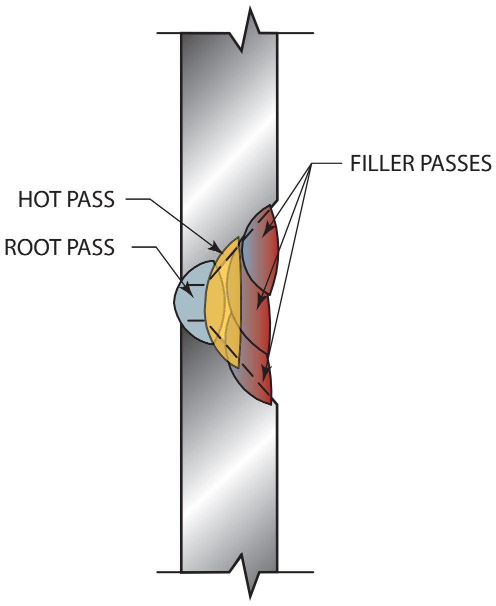


FIGURE 19-25 Weld bead sequence for 2G pipe weld.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 19-16

Single-V Butt Joint (6G Position) 100% Root Penetration to be Tested

Using the same equipment, setup, and materials as listed in Practice 19-13, you will make a welded butt joint on a pipe fixed at a 45° angle (6G) position.

Starting at the bottom, make the root pass upward to the 12:30 o'clock position. The size of the root pass should stay the same; however, it may be off to one side more than the other. As long as the root surface is uniform, this unbalanced appearance is acceptable. The filler passes should correct this problem.

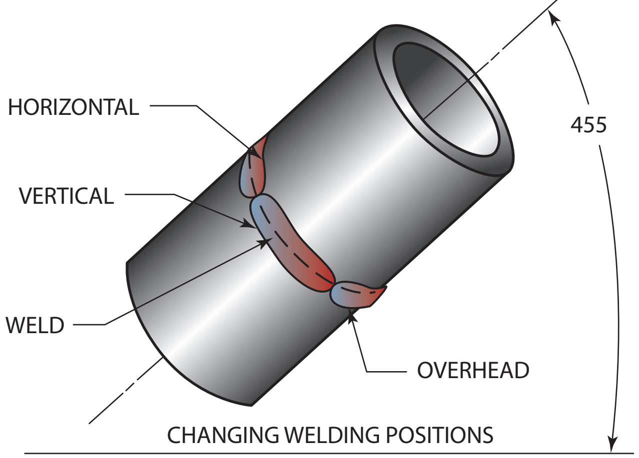


FIGURE 19-26 6G pipe welds contain segments that are classified as overhead, vertical, and horizontal.

The filler passes are applied to the downhill side first so that the upper side will be supported, **Figure 19-26**. The starts and stops should be staggered so that they do not increase the possibility of defects at any one point on the weld. A slight "J" weave pattern will help hold the shape of the bead as it changes from overhead to vertical to horizontal.

The cover pass is easy to control if it is a series of stringer beads. Start on the lower side and build up the cover pass as in the 2G position. Each weld should overlap the preceding weld so that the finished weld is uniform.

After the weld is complete, visually inspect it for uniformity and for any defects. If the weld passes, inspect the root for 100% penetration. If the root passes this inspection, cut out guided-bend test specimens. Test the specimens and evaluate the results. Repeat this practice until both parts A and B can be passed. Turn off the welding machine, shielding gas, and cooling water, and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

Summary

Mastering the GTA welding process so that you are able to make acceptable welds in mild steel, stainless steel, and aluminum is a major accomplishment. Each of the metals reacts differently as they are being welded. Understanding how the heat is conducted away from the weld by each metal is important. The different conductivity of each metal plays a large part in how each metal reacts to being welded and how they might become distorted. Therefore, as you make these welds, watch how each metal reacts so that you can be better able to resolve problems that might arise in the field during GTA welding.

Understanding how each of the metals reacts to being welded will be extremely helpful when you are welding in the field. The welding coupons you are working on in the lab are much easier to weld because there is not as much mass in the surrounding metal, and it is much easier to form a molten weld pool. In addition you may be required to make welds on larger diameter pipes with thicker wall sections, which adds to the difficulty in establishing a weld. Keep in mind that the mass of the metal will affect how the weld pool is formed. It may take a great deal more heat and a larger electrode in the field than the same thickness practice coupon required in the lab.

Having the knowledge and being comfortable with the process will make it much easier for you to make successful welds in the field as you make in the lab.

Review

1. The AWS SENSE Level I Workmanship Qualifications test requires GTA welders to be able to make butt welds in what positions?
2. What skills are needed to successfully complete the SENSE Level I GTA qualification test?
3. What type of inspection must the welds pass?
4. List three items that can be checked during a visual inspection of a butt joint.
5. What is the maximum acceptable size of the face and root reinforcement on butt welds?
6. What is the maximum weld size for lap and tee joint fillet welds?
7. What would be the maximum acceptable depth of undercut on a 1/4-in. (6-mm)-thick metal plate welded in a tee joint?
8. What is the maximum acceptable root face concavity on tubing?
9. Describe how to perform a free bend test to help identify root problems in a weld.
10. What part of a weld is the free bend designed to test?
11. How can the 1-in. (25-mm)-wide strips be cut out of the butt joint test plates?
12. What is the range of diameters of the filler metal in Practice 19-7?
13. What welding current is used on the carbon steel workmanship samples?
14. What are the F-number and A-numbers for the stainless filler metal used in Practice 19-8?
15. Why are solvents or detergents needed?
16. Why might it be necessary to reclean the part and/or the filler metal?
17. What welding current is needed for the GTA welding of aluminum?
18. Why is a lace bead more easily controlled than a weave bead?
19. What advantage is there in making a small root weld?
20. Why should the filler passes on a single-V butt joint be applied to the downhill side first?

Section 5

Related Technologies

Success Story

My name is Ken Leonard. In the early 1980s I was working in Dallas for one of the largest contractors in the world. I was sent two hours from home to work on a nuclear power plant. On any nuclear plant project all of the material used, all of the welders' certifications, and inspection reports etc. must be maintained for every weld. This results in mountains of paperwork, all of which takes many hours away from the actual task of welding. However, without all of the proper paperwork, the final inspection and acceptance of the work cannot be done. Unfortunately, the previous contractor had failed to keep proper paperwork required on the project, so all of their work had to be torn out and completely redone. The regulations were very stringent, and every step had to be documented.

My job was to run a welding crew that re-installed the exhaust ducting to the bathrooms. To be sure, the job we did on the bathroom vents had little to do with the nuclear safety side of the plant. But in a nuclear plant the ductwork has to be welded so that it will not leak if there is an accidental release of radioactive gas at the power plant.

The scheduled startup of the power plant was far behind schedule. To try and make up time we were working ten- and twelve-hour days for 60 to 70 hours a week. The materials, such as welding rods and sheet metal, all had to have certification paperwork from the manufacturer and have identification marking. All of that had to be recorded in the paperwork. It all seemed like overkill for any application; however, that's what killed the last contractor's work.

Every step in the process had to be documented, so my day went like this: The welder would use vise grips to put six-by-six angle iron together to get it ready to weld. Then I would have to stand in line to get an inspector who would look at it; and if he approved, the welder could lay the first bead. Then I had to get an inspector to look at the weld and give us the go-ahead to chip the slag. Again, I would have an inspector give us the green light to lay another bead. Often one duct hanger would take days to complete because this protocol had to be followed without exception. Every nut and bolt we used had to be torqued in front of an inspector who had to seal the threads with wax to prove every widget had been installed with the proper torque. Remember, almost everything we did had been done by a previous contractor once before and had to be removed to start over. It may seem silly, but that was the requirement.

This is an extreme case, but shortcuts cost millions of dollars and helped cause the project to come in years behind schedule. The same principle applies in almost any build. Don't try to save time and money by cutting corners. At best, it can cause a lot more time and money to do it right the second time; and at worst, someone could get hurt. So do it right the first time, and stick to the plans and specifications.

Chapter 20

Shop Math and Weld Cost

OBJECTIVES

After completing this chapter, the student should be able to

- solve basic welding fabrication math problems.
- round numbers.
- convert mixed units, fractions, and decimal fractions.
- reduce fractions and decimal fractions.
- calculate the area and volume of various geometric shapes.
- create a Bill of Materials.

KEY TERMS

common denominator

conversion

decimal fraction

denominator

dimensioning

equation

formula

fraction

mixed units

numerator

rounding

sequence of mathematical operations

shop time

sides

tolerance

vertex

whole numbers

INTRODUCTION

The most common use of math in welding shops is for **dimensioning** and pricing. For dimensioning, most welding shops use the standard or English system with feet, inches, and fractions. A few shops use metric dimensioning. The metric system, abbreviated as SI, comes from the French term *le Système International d'unités*. This system is made up of seven base units, which include units for length, temperature, weight, and so on, **Table 20-1**. For cost estimation, calculations may include labor costs in hours and minutes, material costs measured in pounds and ounces, linear dimensions in feet and inches, area in square feet and inches, and volume measured in cubic feet and cubic inches; they may also include overhead costs as a percentage of the company's cost for insurance, electricity, rent, mortgage payments, and so on.

Although most shops use the standard system, the math functions of addition, subtraction, multiplication, and division of dimensions are easier in the metric system than they are in the standard system because the metric system is a decimal system. The advantage of a decimal system is that a calculator can more easily be used than with the mixed-numbered standard system.

Abbreviations for Units				
Units	Standard		Metric	
Temperature	F	Fahrenheit	C	Celsius
Length	yd ft in.	yard feet inches	m cm mm	meter centimeter millimeter
Weight	lb oz	pounds ounces	kg g	kilogram grams
Liquid	gal qt pt oz	gallons quarts pints ounces	L	liters
Pressure	psi	pounds per square in.	kPa	kilopascal

TABLE 20-1 Common Abbreviations for Units of Measure

Almost all welding shop dimensioning uses **mixed units**. An example of a mixed unit is feet and inches, with inches based on 12 in. to the foot. So, the largest number of inches is 11 because when you add one more inch it becomes 12 in., which is expressed as 1 ft. Other common mixed units are pounds and ounces and hours and minutes. Mixed units present unique problems for addition, subtraction, multiplication, and division because each type of unit must be worked separately.

For example, you cannot add feet to inches without first converting the feet to inches.

Most welding shops encourage the use of calculators because they eliminate arithmetic errors. There are a few calculators that can add, subtract, multiply, and divide standard fractional dimensions, and some can even work mixed units of feet and inches. However, most math using fractions must be worked manually.

For pricing and cost estimating, welders must use math to enable their welding business to operate profitably. The owner or manager must be able to make cost-effective welding decisions. A number of factors affect the cost of producing weldments. Some of these factors include the following:

- Material
- Weld design
- Welding processes
- Finishing
- Labor
- Overhead

SHOP MATH

Mathematics has many branches—calculus, geometry, trigonometry, and so on—but arithmetic is the basic branch of mathematics that is primarily involved with combining numbers by addition, subtraction, multiplication, and division. Arithmetic is the math that most welders use on a daily basis. Welding layout and to some extent fitup may involve geometry and trigonometry. Both of these branches of mathematics deal with angles and points and are related to laying out and fitting up complexly shaped weldments.

TYPES OF NUMBERS

Welders use only a few types of numbers on a regular basis. They most commonly use the following types of numbers.

Whole Numbers

Whole numbers are numbers used to express units in increments of 1, so they can be divided evenly by the number 1. Examples of whole numbers are 1, 2, 3, 4, 5, 6, 7, 8, 9, and 10. They are the easiest type of numbers to use with all types of mathematical functions.

Decimal Fractions

A **decimal fraction** is a number that uses a decimal point to denote a unit that is smaller than 1. Examples of decimal fractions are 0.1, 0.35, 0.9518, 1.1, 5.4, 3.14, and 125.1234. Decimal fractions are expressed in units that are 10 times, 100 times, 1000 times, and so on, smaller than 1, **Figure 20-1**. They can be added and subtracted as easily as whole numbers. Decimal fractions can be used with whole numbers.

Mixed Units

Mixed units are measurements containing numbers that are expressed in two or more different units. An example of a mixed unit is a linear measurement such as 2 ft 6 in., with part of the measurement expressed in feet (2) and the other part in inches (6). Other examples of mixed units are angular measurements such as 45° 0', weight measurements such as 8 lb 4 oz, and time measurements such as 3 hr 20 min 15 sec. The most common types of mixed units used in welding fabrication are linear dimensions, angular dimensions, weight, and time. Linear dimensions use units of feet and inches (SI: meters, centimeters, and millimeters); angular dimensions use degrees, minutes, and seconds; weight uses pounds and ounces (SI: kilograms and grams); and time uses hours, minutes, and seconds. The different units may be separated with a space ( ) or dash (–). It is important to keep the different number units straight when performing mathematical functions.

Fractions

A **fraction** is two or more numbers used to express a unit smaller than one. Examples of fractions are 1/2, 3/4, 5/16, 2 3/8, and 9 1/2. A dash (–) or slash (/) is used

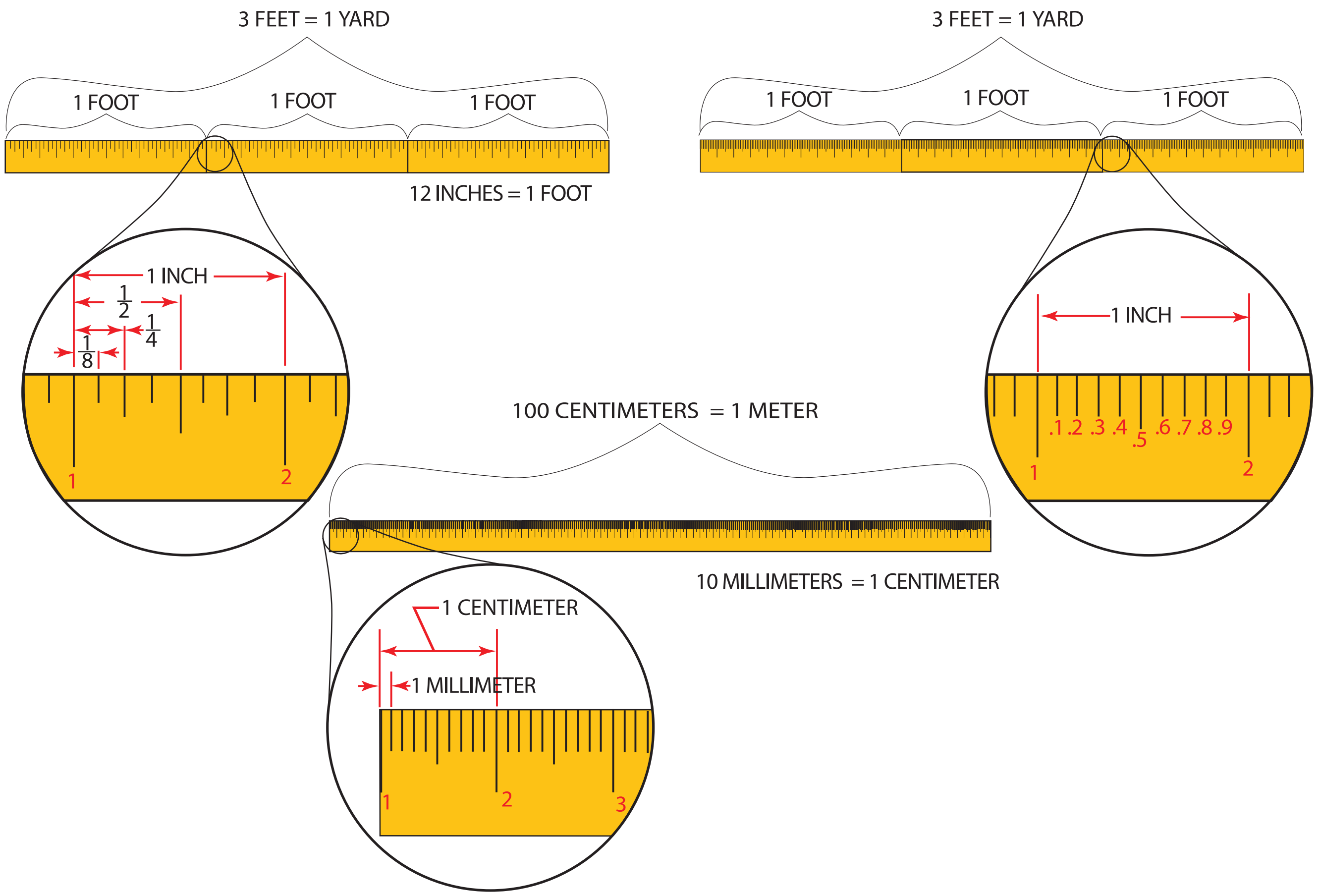


FIGURE 20-1 Number and decimal terminology.

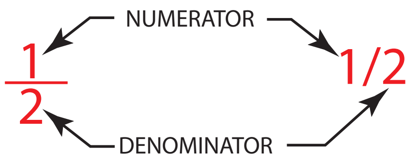


FIGURE 20-2 Fraction identification.

to separate the top and bottom numbers of a fraction. The **denominator** is the bottom number of a fraction, and the **numerator** is the top number, **Figure 20-2**. Fractions can be the hardest type of number to work with because they often cannot be added, subtracted, multiplied, or divided without first having to make some type of **conversion**. Fractions can include whole numbers, such as the "9" in 9 1/2.

GENERAL MATH RULES

All of the math problems in this chapter will be set up and worked in the same manner.

Step 1: The equation or formula will be stated on the first line.
Step 2: "Where" explains the meaning of any variables.
Step 3: State the problem's known values and what answer is needed.
Step 4: Write the equation or formula.
Step 5: Write the known values in place of the variables.
Step 6: One mathematical calculation will be performed per line.
Step 7: Add as many lines as necessary to complete the problem's calculations.
Step 8: Give the answer, including units.
Step 9: Explain the answer in a written statement.

When working a math problem by hand, write them down in a vertical series of lines with each individual step on a line. Keeping the equal symbol on each line lined up vertically will reduce confusion and make it easier to refer back to the problem later. Working math problems in this very structured way makes it easier for you to look back at the examples in this textbook and work new problems you might encounter in a welding shop. Years later, it can be very frustrating to know the equation or formula but not remember the sequence of mathematical steps.

Letters, Numbers, and Symbols

Letters, numbers, and symbols are often used as expressions in equations and formulas to make it easier to write out the formula. For example, to find the area of a plate you would multiply length times width. However, if you assigned a letter to each of the variables, writing the formula can be made clearer. So, if we assign the letter A for area, the letter L for length, and the letter W for width, the formula can be written $A = L \times W$.

Superscript and Subscripts

Sometimes formula expressions will have a superscript. Superscripts can be numbers or letters written to the upper right of a formula expression such as the 2 in the expression 3^2. In this case, it means that the number 3 is squared, or multiplied by itself two times. Expressions may also have a subscript. Subscripts can be numbers or letters written to the lower right of an expression. They are often used to define the expression such as the term *weld* in the expression CS_{weld}. In this case, it is identifying the CS (cross-section) as that of the weld. Some of the formula expressions used in this textbook are shown in **Table 20-2**.

Expression		Meaning
b	=	base dimension of weld
BD	=	bead depth
BOR	=	burn-off rate in pounds per hour
CS_{root}	=	cross-sectional area of the root opening
CS_{weld}	=	cross-sectional area of the weld
DE	=	deposit efficiency
DR	=	deposition rate in pounds per hour
EL	=	electrode length
GV	=	groove volume
h	=	height dimension of weld
LOCH	=	labor and overhead cost per hour
l	=	length dimension of weld
MD	=	metal density (weight of metal in pounds per cubic inch)
OF	=	operating factor in decimal percent
%DE	=	percentage of weld deposition efficiency
PT	=	plate thickness
RG	=	root gap
RO	=	root opening
SL	=	stub loss
TCS	=	total cross sectional area
TLOC	=	total labor and overhead cost
$Wt_{electrode\ used}$	=	weight of electrode used
$Wt_{weld\ metal}$	=	weight of weld metal
LH	=	weld leg height
LW	=	weld leg width
WL	=	weld length

TABLE 20-2 Formula Expressions Used in this Textbook

EQUATIONS AND FORMULAS

Equations

An **equation** is a mathematical statement in which both sides are equal to each other; for example, $2X = 1Y$. In this equation, the value of X is always going to be 1/2 of the value of Y. An example of an equation used in metal fabrication would be: *the number of hours worked (hr) × pay per hour (\$) = total labor bill (T), or hr × \$ = T.* If either the hours or the pay rate goes up, then the total bill also goes up, and vice versa.

To find the labor cost, use the following equation:

$$hr \times \$ = T$$

Where:

hr = hours worked
\$ = hourly rate
T = total labor bill in dollars

Find the total labor bill for 4 hours of work at \$15 per hour, **Figure 20-3**.

$$hr \times \$ = T$$
$$4 \times 15 = T$$
$$60 = T$$

The total pay (T) for the 4 hours of work at \$15 per hour would be \$60.

Formulas

A **formula** is a mathematical statement of the relationship of items. It also defines how one cell of data relates to another cell of data, for example, wt = [(l" × w" × t") ÷ 1728] × wt/ft. In this formula you must first find the volume of material by multiplying length (l) times width (w) times thickness (t) before dividing that number by the number of cubic inches in a cubic foot (1728), then multiply that number by the material's weight per cubic foot (wt/ft). The **sequence of mathematical operations** is important when working formulas and equations. The two examples below have significantly different answers and both are correct. In the first example without parentheses all of the mathematical operations start at the left and move to the right. In the second example the parentheses control the sequence of operation. Even though the numbers are the same in both examples, the answers are different.

Example 20-1A $6 \times 4 \div 2 \times 5 = 60$,

Step 1. $6 \times 4 = 24$
Step 2. $24 \div 2 = 12$
Step 3. $12 \times 5 = 60$

JOB CARD		
Job Weld out Go Cart Frame	Date 1/4	Welder lfj
Starting Time	Ending Time	Total Time
7:00 am	11:00 am	4 hrs
	Total Hours	4 hrs
	Hourly Rate	× $23/hr
	Total Labor	$92.00

FIGURE 20-3 Bill of Materials.

but

Example 20-1B $(6 \times 4) \div (2 \times 5) = 2.4,$

Step 1. $(6 \times 4) = 24,$
Step 2. $(2 \times 5) = 10,$
Step 3. $24 \div 10 = 2.4.$

When a formula has more than one mathematical operation, the operations must be performed in the following order:

1. Perform all operations within parentheses.
2. Resolve any exponents.
3. Do all multiplication and division working from left to right.
4. Do all addition and subtraction working from left to right.

To find the total weight of a piece of material, use the following formula:

$$wt = [(l'' \times w'' \times t'') \div 1728] \times wt/ft$$

Where:

wt = total weight
l" = length in inches
w" = width in inches
t" = thickness in inches
1728 = number of cubic inches in a cubic foot
wt/ft = weight of material in pounds per cubic foot

Find the total weight of a piece of steel that is 144 in. (365.76 cm) long, 12 in. (30.48 cm) wide, and 2 in. (5.08 cm) thick if steel weighs 490 lb per cubic foot (7847 kg per cubic meter):

Standard Units

$$wt = [(l'' \times w'' \times t'') \div 1728] \times wt/ft$$
$$wt = [(144 \times 12 \times 2) \div 1728] \times 490$$
$$wt = [(1728 \times 2) \div 1728] \times 490$$
$$wt = [(3456) \div 1728] \times 490$$
$$wt = 2 \times 490$$
$$wt = 980$$

SI Units

$$wt = [(l\ cm \times w\ cm \times t\ cm) \div 1{,}000{,}000] \times wt/m$$
$$wt = [(365.76\ cm \times 30.48\ cm \times 5.08\ cm) \div 1{,}000{,}000] \times 7847$$
$$wt = [(11{,}148.36 \times 5.08) \div 1{,}000{,}000] \times 7847$$
$$wt = [(56{,}633.69) \div 1{,}000{,}000] \times 7847$$
$$wt = 0.06 \times 7847$$
$$wt = 444.4$$

1,000,000 is the number of cubic centimeters in a cubic meter. The total weight of this piece of steel is 980 lb (444.4 kg).

MIXED UNITS

The problems caused while working with mixed numbers in the standard system do not exist in the metric system because the metric system is based on 10. In the metric system, to change the base unit all you have to do is move the decimal point. For example, 25.4 mm is 2.54 cm and 100 mg is 10.0 g. However, in the standard system converting inches to feet or ounces to pounds is more complex because inches to feet is base 12 and ounces to pounds is base 16. So, when adding mixed units such as feet and inches, you have to add each type of number together first. For example, you would add the inches to inches and feet to feet.

Adding and Subtracting Mixed Units

An example of a mixed unit problem you might find in welding would be to see how many feet of metal stock you need if one piece is 10 ft 6 in. long and the other is 3 ft 5 in. long, **Figure 20-4**. The first step would be to write the numbers in columns with feet over feet and inches over inches. The second step would be to add the inches to the inches and feet to the feet.

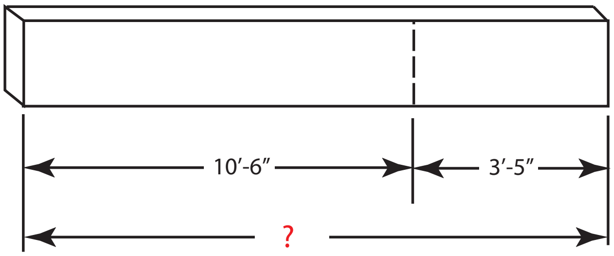


FIGURE 20-4 Adding mixed numbers.

Add 10'6" + 3'5"

	Feet Column	Inch Column
Step 1	10'	6"
Step 2+	3'	5"
	13'	11"

Or

Add 10'6" + 3'5"

Step 1: 10' + 3' = 13'
Step 2: 6" + 5" = 11"
Step 3: 13' + 11" = 13' 11"

When subtracting mixed units, use the same steps as were used for adding. For example, to see how many feet of scrap pipe you have left from a 7-ft 8-in. piece when 5 ft 3 in. will be cut off, **Figure 20-5**, you would do the following:

Subtract 7' 8" − 5' 3"

	Feet Column	Inch Column
Step 1	7'	8"
Step 2	−5'	3"
	2'	5"

or

Subtract 7' 8" – 5' 3"

Step 1: 7' − 5' = 2'
Step 2: 8" − 3" = 5"
Step 3: 2' + 5" = 2' 5"

When some mixed units are added, the sum can be reduced. For example, if you add 7 in. to 7 in., the total would be 14 in., which is the same as 1 ft 2 in. To reduce

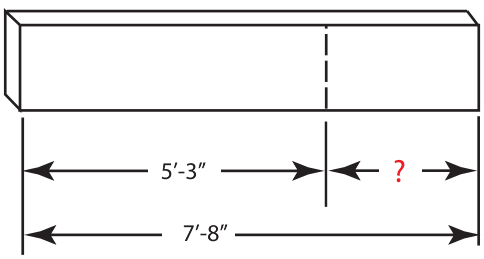


FIGURE 20-5 Subtracting mixed numbers.

Feet and Inches		Pounds and Ounces	
Ft Fraction	Inches	Lb Fraction	Ounces
1/12	1	1/16	1
2/12	2	2/16	2
3/12	3	3/16	3
4/12	4	4/16	4
5/12	5	5/16	5
6/12	6	6/16	6
7/12	7	7/16	7
8/12	8	8/16	8
9/12	9	9/16	9
10/12	10	10/16	10
11/12	11	11/16	11
12/12	12	12/16	12
		13/16	13
		14/16	14
		15/16	15
		16/16	16

TABLE 20-3 Feet and Inches and Pounds and Ounces

any inches equal to or larger than 12 in. to feet and inches, you divide the inches by 12. For example, how long will a piece of steel bar need to be if you are going to cut both a 7-ft 8-in. piece and a 6-ft 6-in. piece from it? Reduce the answer in inches to feet and inches using **Table 20-3**. Pounds and ounces are also mixed units, which can be reduced by dividing the ounces by 16.

Add 7' 8" + 6' 6"

	Feet Column	Inch Column
Step 1	7'	8"
Step 2 +	6'	6"
	13'	14"
Reduce and Add		
Step 3	13'	14 ÷ 12
Step 4	13 + 1	2
Step 5	14'	2"

or

Add 7'8" + 6'6"

Step 1: 7' + 6' = 13'
Step 2: 8" + 6" + 14"
Step 3: 13' + 14" = 13' 14"

Reduce 14" to feet and inches

Step 4: 14 ÷ 12 = 1' and 2/12"
Step 5: 2/12 = 2"

Re-add 13' 0" + 1' 2"

Step 6: 13' + 1' = 14'
Step 7: 0" + 2" = 2"
Step 8: 14' + 2" = 14' 2"

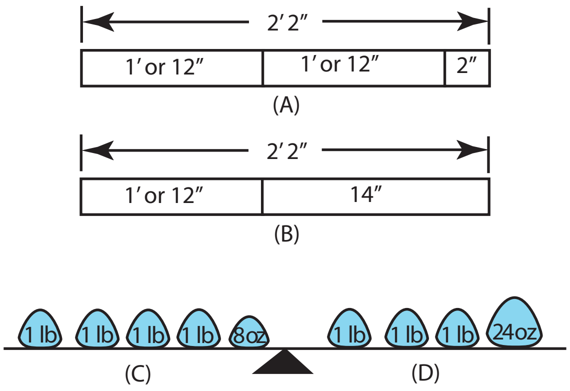


FIGURE 20-6 Mixed units.

When subtracting one mixed unit from another and when the small unit being subtracted is larger than the small unit it is being subtracted from—for example, 1 ft 4 in. from 2 ft 2 in.—you must make that unit larger. You can increase the small unit in a mixed number by subtracting one whole large unit by dividing it into the smaller units. For example, 2 ft 2 in. **(Figure 20-6A)** is the same dimension as 1 ft 14 in. **(Figure 20-6B**), and 4 lb 8 oz **(Figure 20-6C)** is the same weight as 3 lb 24 oz **(Figure 20-6D).**

Convert 2' 2"

Step 1: 2' = 1' 12"
Step 2: 1' 12" + 2" = 1' 14"

Convert 4 lb 8 oz

Step 1: 4 lb = 3 lb 16 oz
Step 2: 3 lb 16 oz + 8 oz = 3 lb 24 oz

With 2 ft 2 in. converted to 1 ft 14 in., you can now subtract 1 ft 4 in. the same way as you subtracted mixed numbers before.

Subtract 1' 14" − 1' 4"

Step 1: 1' − 1' = 0'
Step 2: 14" − 4" = 10"
Step 3: 0' + 10" = 10"

To subtract 2 lb 10 oz from 4 lb 8 oz, you have to convert 1 lb to 16 oz and add that to the 8 oz as shown in Figure 20-6C and Figure 20-6D. Now, 4 lb 8 oz has become 3 lb 24 oz.

Subtract 3 lb 24 oz − 2 lb 10 oz

Step 1: 3 lb − 2 lb = 1 lb
Step 2: 24 oz − 10 oz = 14 oz
Step 3: 1 lb + 12 oz = 1 lb 14 oz

When adding multiple mixed numbers, add all of the inches first and then all of the feet. Then, reduce the inches to feet and add the new mixed number to get the final answer. Follow the same process when adding pounds and ounces. Find the total length of angle iron needed if the following pieces are to be cut out.

Add 2' 6" + 5' 6" + 7' 3" + 8' 2" + 1' 1" + 3' 9"

Step 1	Feet Column	Inch Column
	2'	6"
	5'	6"
	7'	3"
	8'	2"
	1'	1"
Step 2 +	3'	9"
	26'	27"

Reduce and Add

Step 3	26'	27 ÷ 12
Step 4	26 + 2	3
Step 5	28'	3"

or

Add 2' 6" + 5' 6" + 7' 3" + 8' 2" + 1' 1" + 3' 9"

Step 1: 2' + 5' + 7' + 8' + 1' + 3' = 26'
Step 2: 6" + 6" + 3 + 2" + 1" + 9" = 27"

Reduce 27" to feet and inches

Step 3: 27 ÷ 12" = 2' 3/12"
Step 4: 3/12" = 3"

Add 26' 0" + 2' 3"

Step 5: 26' + 2' = 28'
Step 6: 0" + 3" = 3"
Step 7: 28' + 3" = 28' 3"

Fractions

Fractions are commonly used in welding fabrication for dimensioning a distance that is less than an inch. **Figure 20-7** shows the common inch fractions most often used in welding fabrication. Because it is difficult for most manual welding to work with fractions smaller than 1/16 of an inch, such as 1/32 and 1/64 of an inch, these smaller dimensions are not commonly used in fabrication. When they are used, it is most often with some form of automated or machine welding or cutting process.

Finding the Fraction's Common Denominator

When the denominators of two fractions to be added or subtracted are different, one or both must be converted so that both denominators are the same. To convert a denominator, multiply both the numerator and the denominator of

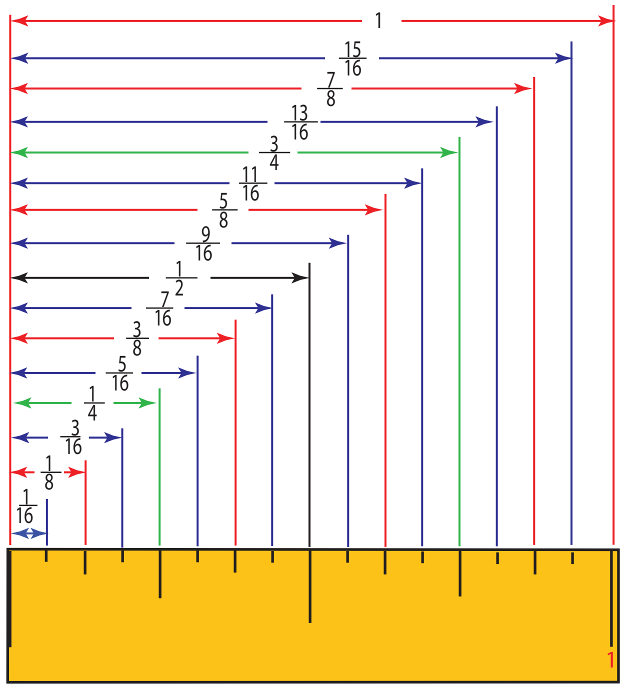


FIGURE 20-7 Fractions of an inch.

Inch	Halves	Fourths	Eighths	Sixteenths
				1/16
			1/8	2/16
				3/16
		1/4	2/8	4/16
				5/16
			3/8	6/16
				7/16
	1/2	2/4	4/8	8/16
				9/16
			5/8	10/16
				11/16
		3/4	6/8	12/16
				13/16
			7/8	14/16
				15/16
1	2/2	4/4	8/8	16/16

TABLE 20-4 Converting Fractions to a Common Denominator

the fraction by the same number. For example, to convert 1/4 to 16ths, you would multiply both the numerator and denominator by 4: $4 \times 1 = 4$ and $4 \times 4 = 16$, which is 4/16. There are conversion tables available to convert the denominators and numerators, **Table 20-4**. To add 1/2 and 1/16, where both denominators are different, you must first find the **common denominator**. In this case it is 16.

$$\text{Convert the Fraction } \frac{1}{2} = \frac{8}{16}$$

$$\text{Add } \frac{8}{16} + \frac{1}{16}$$

$$\frac{8+1}{16}$$

$$\frac{9}{16}$$

Reducing Fractions

Some fractions can be reduced to a smaller denominator. For example, 4/8 is the same as 1/2, although when you are working with a rule or tape measure on the job, you can locate either measurement. Reductions may be necessary only when you are adding or subtracting several different dimensions or various fractional units.

NOTE

It is important to be able to communicate clearly on the job. For example, you would want to reduce the fraction and ask for a 3/8-in.-thick piece of steel, not a 6/16-in.-thick piece of steel.

The normal way to reduce a fraction is to find the largest number that can be divided into both the denominator and numerator. If you are good at math, then that can be easily done; however, if you are not good at doing math in your head, then there is an alternate way of reducing fractions. For reducing fractions in a welding fabrication shop, it is often easiest to divide both the numerator and denominator by 2. This method will simplify the reduction because all the fractional units found on shop rules and tapes are divisible by 2, for example, halves, fourths, eighths, sixteenths, and thirty-seconds. Using this method may require more than one reduction, but the simplicity of dividing by 2 offsets the time needed to repeat the reduction. For example, both the denominator and numerator of 4/8 can be divided by 2, so $4 \div 2 = 2$ and $8 \div 2 = 4$. That would make the new fraction 2/4, which can be reduced again by dividing the denominator and numerator one more time by 2. This last division results in 2/4 being reduced to 1/2. Reduction of fractions becomes easier with practice. Reduce 14/16 and 4/16 to their lowest common denominators.

Multiplying and Dividing Fractions

Although there is a way to multiply and divide fractions, the easiest way is to convert the fraction to a decimal fraction and, if needed, convert it back to a fraction once you have an answer. By converting the fraction to a decimal fraction, you can easily use a calculator to do the math. One slight problem with doing that is that some fractions when converted to decimal fractions and then divided can result in recurring decimals; for example, 1/3 becomes 0.333333333. If you add $0.333333333 + 0.333333333 + 0.333333333$, you get 0.999999999, which is not equal to 1, but if you add $1/3 + 1/3 + 1/3$, you get 3/3, which is 1. But realistically, 0.999999999 is only 0.000000001 less than 1, and most welding fabrication uses a dimensional **tolerance** of ±1/16 to ±1/8, which is a lot larger than

Inch Fraction	Inch Decimal	mm
1/16	1.5875	0.062500
1/8	3.1750	0.125000
3/16	4.7625	0.187500
1/4	6.3500	0.250000
5/16	7.9375	0.312500
3/8	9.5250	0.375000
7/16	11.1125	0.437500
1/2	12.7000	0.500000
9/16	14.2875	0.562500
5/8	15.8750	0.625000
11/16	17.4625	0.687500
3/4	19.0500	0.750000
13/16	20.6375	0.812500
7/8	22.2250	0.875000
15/16	23.8125	0.937500
1	25.4000	1.000000

TABLE 20-5 Conversion of Fractions, Decimals, and Millimeters

that. **Table 20-5** lists the conversions for most fractions to decimal fractions. Also, converting fractions to decimal fractions and converting decimal fractions back to fractions are covered later in this chapter.

CONVERTING NUMBERS

Dimensions on a drawing are usually given in a consistent format and unit type. For example, everything would be standard units or metric units. Very seldom will you find that you must make conversions when reading a drawing. However, you may be asked to install or mount a unit such as a winch on a truck bumper or motor on a piece of equipment. If the part's drawing is dimensioned in metric and you are working in standard units, you may be able to simply measure the part using a tape or rule of the same measurement type as your drawing. Sometimes you will be working from the manufacturer's drawing, and then you may have to make conversions of measurements.

Conversion of measurements is also often used to make it easier to lay out the part. Conversions can also be used to reduce confusion with your coworkers on a job. It is much easier to understand 1 1/8 in. rather than trying to find 9/8 in. on a scale, even though they are the same.

Converting Fractions to Decimals

From time to time it may be necessary to convert fractional numbers to decimal numbers. A fraction-to-decimal conversion is needed before most calculators can be used to solve problems containing fractions. There are some calculators that will allow the inputting of fractions without converting them to decimals.

Rule: To convert a fraction to a decimal, divide the numerator (top number in the fraction) by the denominator (bottom number in the fraction) or use a conversion chart.

To convert 3/4 to a decimal:

$$3 \div 4 = 0.75$$

To convert 7/8 to a decimal:

$$7 \div 8 = 0.875$$

Tolerances

All measuring, whether on a part or on the drawing, is in essence an estimate because no matter how accurately the measurement was made, there could always be a more accurate way of making it. Dimensioning tolerance is the difference between the exact dimension as shown on a drawing and the actual acceptable size of a part. The more accurate the measurement, the more time it takes. Drawings may state a dimensioning tolerance, the amount by which the part can be larger or smaller than the stated dimensions and still be acceptable. Tolerances are usually expressed as plus (+) and minus (−). If the tolerance is the same for both the plus and the minus, it can be written using the symbol ± (pronounced plus or minus), **Table 20-6**. In addition to the tolerance for a part, there may be an overall tolerance for the completed weldment. This dimension ensures that if all the parts are either too large or too small, their cumulative effect will not make the completed weldment too large or too small. Most weldments use a tolerance of ± 1/16 in. or ± 1/8 in., **Figure 20-8**.

Converting Decimals to Fractions

This process is less exact than the conversion of fractions to decimals. Except for specific decimals, the conversion will leave a remainder unless a small enough fraction is selected. For example, the decimal 0.765 is very close to the decimal 0.75, which easily converts to the fraction 3/4. The difference between 0.765 and 0.75 is 0.015 (0.765 − 0.75 = 0.015), which is within the acceptable tolerance for most welding applications. If you are working to a ± 1/8-in. (3-mm) tolerance that has up to a 1/4 in. (6 mm) difference from the minimum to maximum dimensions, then a measurement of 3/4 is acceptable. More accurately, 0.765 can be converted to 49/64 in., a

		Acceptable Dimensions	
Dimension	Tolerance	Minimum	Maximum
12″	±1/8″	11 7/8″	12 1/8″
2′ 8″	±1/4″	2′ 7 3/4″	2′ 8 1/4″
10′	±1/8″	9′ 11 7/8″	10′ 1/8″
11″	±0.125	10.875″	11.125″
6′	±0.25	5′ 11.75″	6′ 0.25″
250 mm	±5 mm	245 mm	255 mm
300 mm	+ 5 mm–0 mm	300 mm	305 mm
175 cm	±10 mm	174 cm	176 cm

TABLE 20-6 Examples of Tolerances

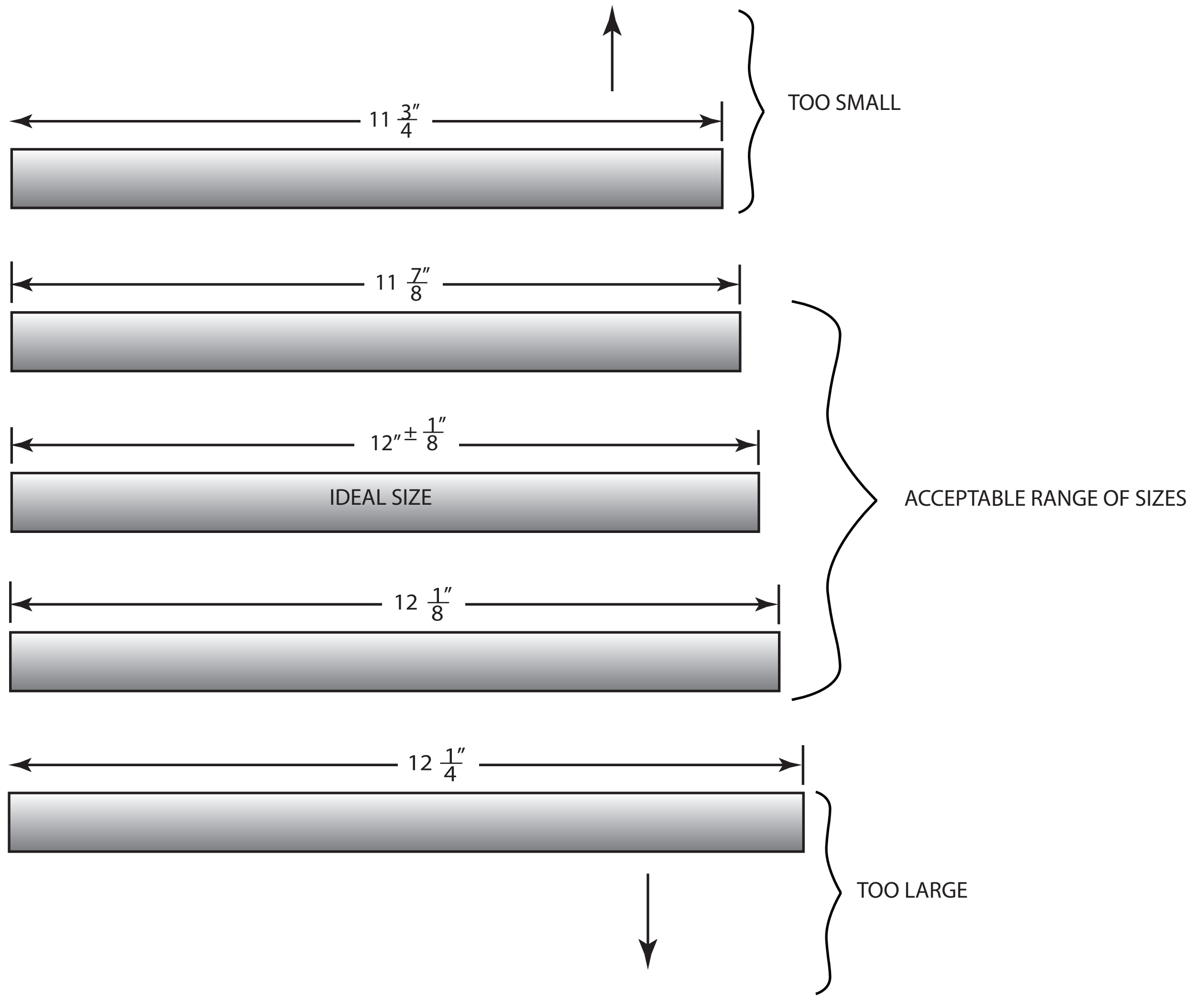


FIGURE 20-8 Tolerances.

dimension that would be difficult to lay out and impossible to cut using a hand torch.

RULE: To convert a decimal to a fraction, multiply the decimal by the denominator of the fractional units desired; that is, for eighths (1/8) use 8, for fourths (1/4) use 4, and so on. After multiplying, place the product (dropping or **rounding** off the decimal remainder) over the fractional denominator used as the multiplier.

To convert 0.75 to fourths:

$$0.75 \times 4 = 3.0 \text{ or } 3/4$$

To convert 0.75 to eighths:

$$0.75 \times 8 = 6.0 \text{ or } 6/8, \text{ which will reduce to } 3/4$$

To convert 0.51 to fourths:

$$0.51 \times 4 = 2.04 \text{ or } 2/4, \text{ which will reduce to } 1/2$$

Conversion Charts

Occasionally a welder must convert the units used on the drawing to the type of units used on the layout rule or tape. Fortunately, charts are available that can be used to easily convert between fractions, decimals, and metric units. To use these charts, Table 20-5, locate the original dimension and then look at the dimension in the adjacent column(s) of the new units needed. Both metric-to-standard conversions and standard-to-metric conversions result in answers that often contain long strings of decimal numbers. Often this new converted number, because of the decimals now attached to it, cannot be easily located on the rule or tape. In addition, most of the layout and fabrication work welders perform does not require such levels of accuracy. When a weldment's specifications do call for an accuracy that is more critical or accurate than can expected to be laid out with a steel rule and marker, the parts are often machined to size after welding.

ANGLES

An angle is formed by two lines called **sides** that radiate outward from a single point called the **vertex**, **Figure 20-9**. A circle is made up of 360 equally spaced lines radiating outward from the central point. The angular spacing

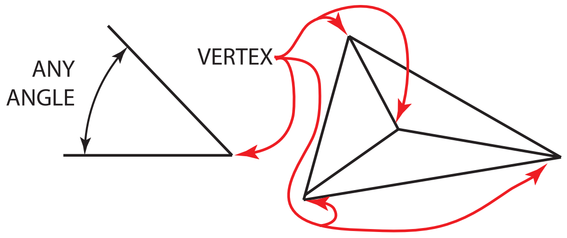


FIGURE 20-9 Vertex and angle lines.

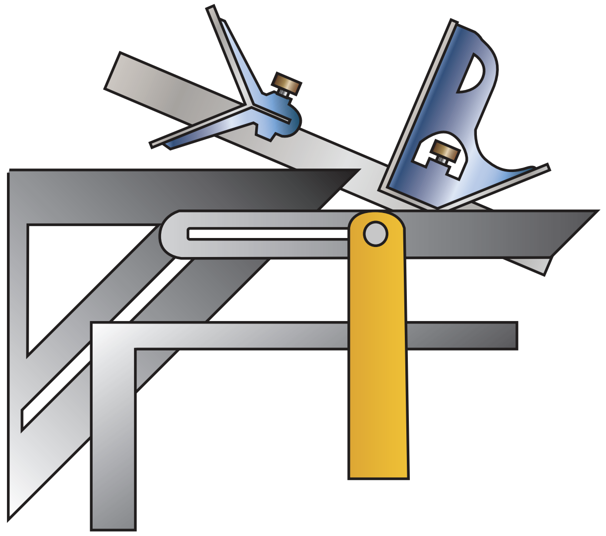


FIGURE 20-11 There are many different types of layout tools.

between each of these lines is called 1 degree, **Figure 20-10A**. The further the distance out any two radii are, the greater the distance between them; however, the angular dimension in degrees stays the same. Each degree of a circle can be divided into 60 equal dimensions called minutes, **Figure 20-10B**. Each minute can be divided into 60 equal dimensions called seconds, **Figure 20-10C**.

Some of the applications of angles in welding are to lay out a part for cutting, locate a spot to be drilled, or align parts for welding. Most often, welders do not have to calculate angles using math because the information needed can be found on the drawings, or one of many angular layout tools can be used. These tools can range from a common protractor to one of many specialized welding layout and fabrication tools, **Figure 20-11**.

Adding and Subtracting Angles

The mathematical process of adding or subtracting angles is similar to any other mixed units such as feet and inches or pounds and ounces, **Figure 20-12**.

TRIANGLES

Right Triangle

A right triangle is a triangle that has one of its angles at 90° between two of its sides, **Figure 20-13**. The equation used to find the hypotenuse (long side) of a right triangle is known as the Pythagorean theorem, ($a^2 + b^2 = c^2$), **Figure 20-14**. Welders often use this equation to check to see that a corner is square by first measuring 4 ft in one direction and 3 ft in the other. If the corner is square, then the distance between the two points should be 5 ft,

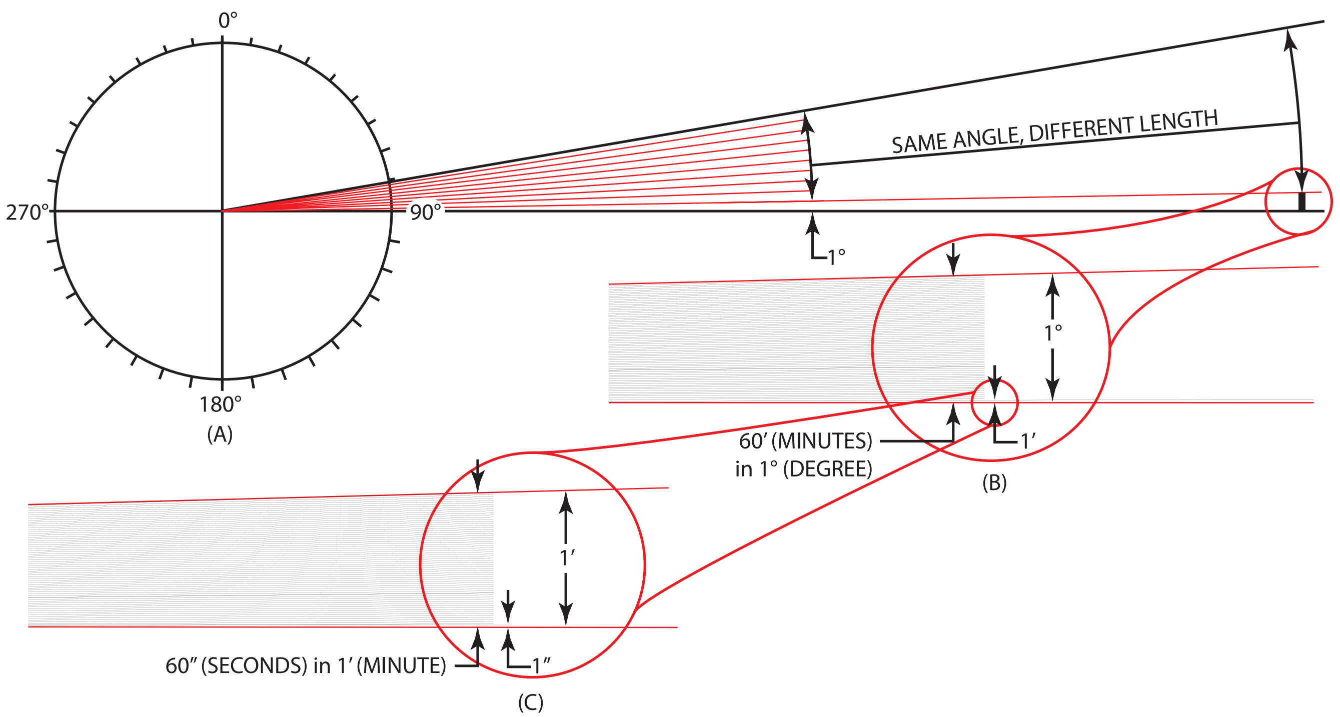


FIGURE 20-10 Degrees, minutes, and seconds.

A. These exercises require the addition of angles. Determine the value of each.

1.	2.	3.	4.
22°11′	22°19′	27°49′	46°12′
+ 62°57′	+ 62°54′	+ 67°36′	+ 76°49′

5.	6.	7.	8.
96°26′	24°33′	11°43′	27°24′24″
+ 24°51′	+ 11°50′	+ 96°46′	+ 57°15′45″

B. These exercises require the subtraction of angles. Determine the value of each.

9.	10.	11.	12.
22°11′	92°19′	97°49′	46°12′
– 12°57′	– 52°54′	– 64°36′	– 34°49′

13.	14.	15.	16.
96°26′	24°03′	11°43′	27°24′43″
– 74°41′	– 11°04′	– 6°46′	– 17°15′45″

FIGURE 20-12 Adding and subtracting angles.

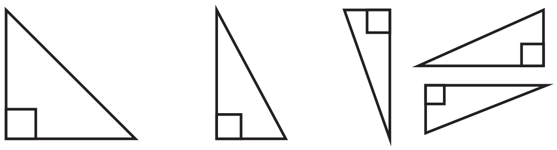


FIGURE 20-13 Right triangles

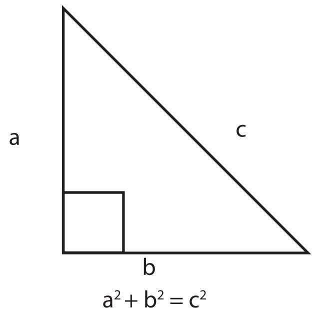


FIGURE 20-14 Pythagorean theorem.

(4 squared + 3 squared = 5 squared), **Figure 20-15**. The numbers 6, 8, and 10 also work; try putting them into the equation to see how they work.

Equilateral Triangle

All three sides of an equilateral triangle are the same length, **Figure 20-16**. Each of the angles is 60°. When added together, they equal 180°, and the internal sum of the angles of all triangles is 180°.

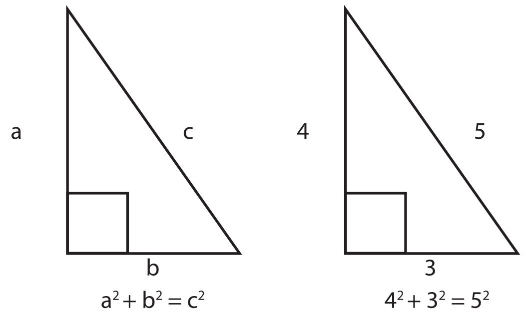


FIGURE 20-15 Using the Pythagorean theorem.

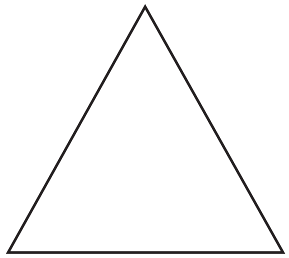


FIGURE 20-16 Equilateral triangle.

Isosceles Triangle

An isosceles triangle has two sides that are the same length and two angles that are the same, **Figure 20-17**. An isosceles triangle is often used to lay out the holes on a circular weldment, such as a hatch cover or pipe blank off, **Figure 20-18**.

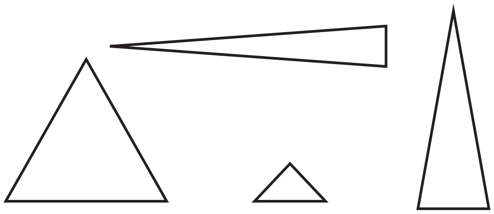


FIGURE 20-17 Isosceles triangle.

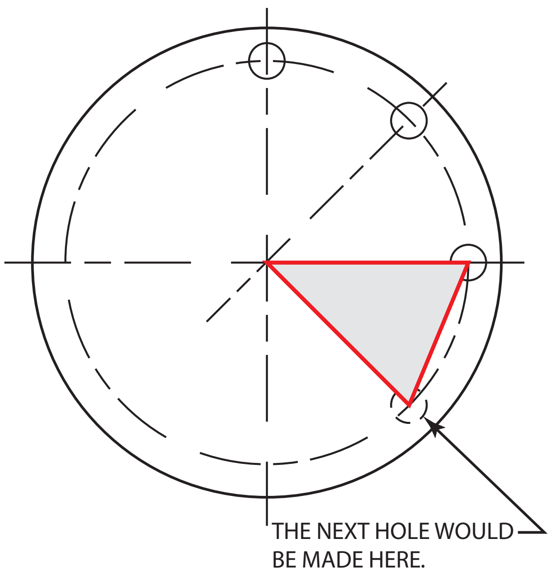


FIGURE 20-18 Using isosceles triangles.

PERIMETER

The distance around the outside edge of a weldment is its perimeter. The perimeter of a weldment must be known any time it will have sides. The length of the perimeter must be known to determine how long it will take to cut out a part based on the speed of the cutting process.

The perimeter is calculated by finding the sum of all of the individual sides of an object, **Figure 20-19**.

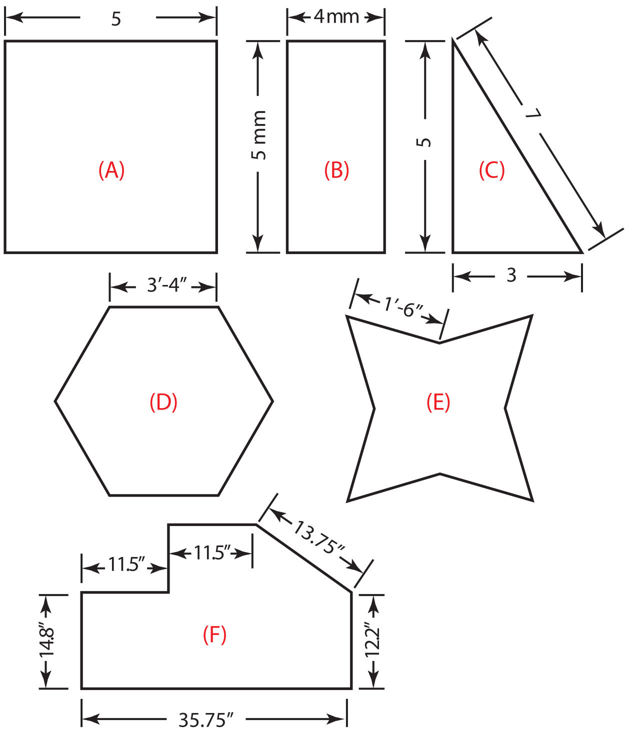


FIGURE 20-19 Perimeter.

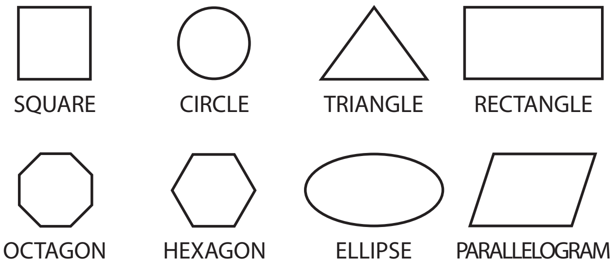


FIGURE 20-20 Area.

AREA

It may be necessary to know the area of a part's surface. Most sheet metal is priced and sold by the square foot or meter. Hard surfacing and surface finishing both require that the welder know the size of the area to be covered. **Figure 20-20** illustrates the eight most common geometric shapes and the formula for calculating their areas. Area is always expressed as square inches (in^2), feet (ft^2), or yards (yd^2) (mm^2, cm^2, or m^2).

PRACTICE 20-1

Calculate the Area Using a Calculator

In this Practice you will calculate the area of the shapes shown in **Figure 20-21**. Use a pencil, paper, calculator with a square root and cube root function, and the formulas shown in **Figure 20-22**. ◆

VOLUME

From time to time, it may be necessary to know the volume of pipes, cylinders, tanks, boxes, and other shaped weldments. The volume of a pipe is needed to calculate how

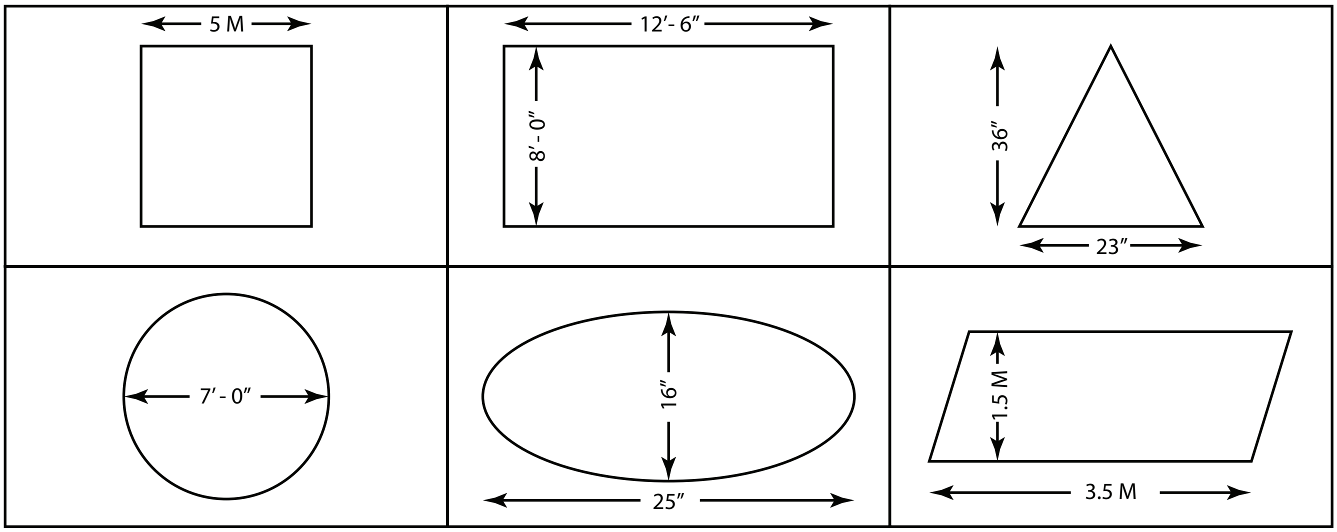


FIGURE 20-21 Practice 20-1.

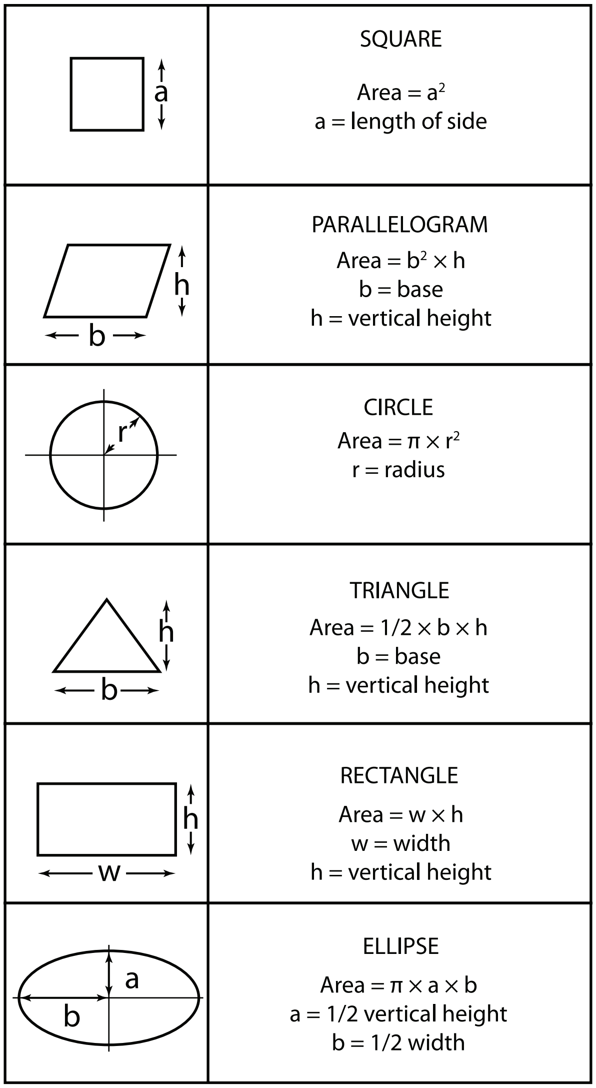


FIGURE 20-22 Area formulas.

Larry Jeffus

FIGURE 20-23 Geometric shapes volume.

much backing gas would be needed to protect the inside of a root pass. It was also needed for fabricating the floating dock air tanks and for the air tanks that lift the boat in a boat slip, **Figure 20-23**.

Finding the volume is easy once you have the area of one end, $V = A \times D$. The volume is expressed in cubic measurements such as cubic in. (in.^{3}), cubic feet (ft^3), or cubic yards (yd^3) (mm^3, cm^3, or m^3).

PRACTICE 20-2

Calculate the Volume Using a Calculator

In this Practice you will calculate the volume of the shapes shown in **Figure 20-24**. Use a pencil, paper, calculator with a square root and cube root function, and the formulas shown in **Figure 20-25**. ◆

Measuring

Measuring for most welded fabrications does not require accuracies greater than what can be obtained with a steel rule or a steel tape, **Figure 20-26**. Tape measures and steel rules are available in standard units, decimal fractions, and metric units. Some may even have two or more different

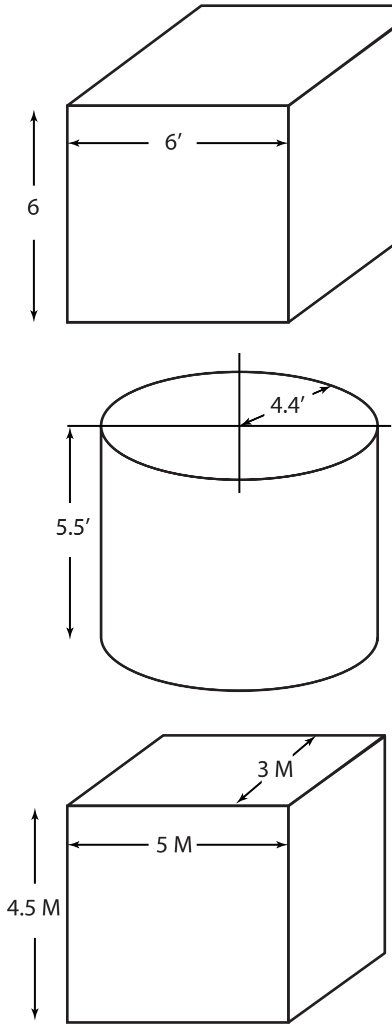


FIGURE 20-24 Practice 20-2.

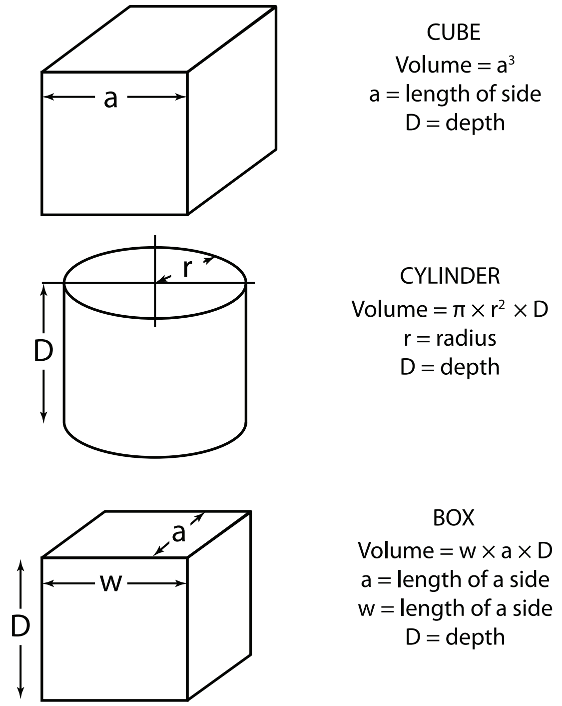


FIGURE 20-25 Volume formulas.

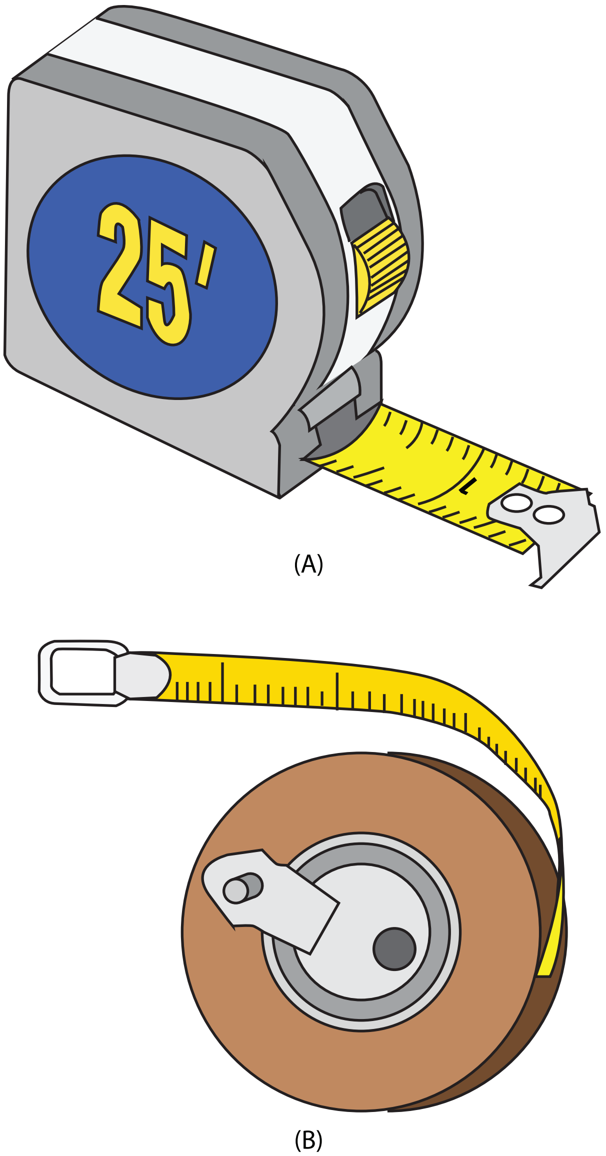


FIGURE 20-26 Measuring tape.

measuring units on the same tape. Using tapes and rules with multiple measuring units can make laying out weldments much easier when you are working with drawings and parts that have different unit measuring systems.

WELDING COSTS

Estimating the costs of welding can be a difficult task because of the many variables involved. One approach is to have a welding engineer specify the type and size of weld to withstand the loads that the weldment must bear. Then, the welding engineer must select the welding process and filler metal that will provide the required welds at the least possible cost. This method is used in large shops, where welding on a product can range from a few thousand dollars to well over a million dollars. With competition for work resulting in small profit margins, each job must be analyzed carefully.

The second approach, used by smaller shops, is to get a price for the materials and then estimate the production time. Process and filler metal costs are considered, but little thought is given to the hidden costs of equipment depreciation, joint efficiency, power, and so on. With the majority of the welding jobs in these shops taking from a few hours to a few days, and with costs ranging from a few hundred dollars to a few thousand dollars, extensive cost analysis cannot be justified. Extensive estimating may take more time than the job itself. To remain profitable *and* competitive, some cost estimation is required. Only the cost considerations that a small shop should consider when estimating a job are covered in this section.

COST ESTIMATION

A number of factors affect welding cost. These factors can be divided into two broad categories: fixed and variable. *Fixed costs* are those expenses that must be paid each and every day, week, month, or year, regardless of work or production. Examples of fixed costs include rent, taxes, insurance, and advertising. *Variable costs* are those expenses that change with the quantity of work being produced. Examples of variable costs include supplies, utilities, labor, and equipment leases. Expenses within both categories must be considered when making welding job estimates. These cost areas include the following:

- *Material cost:* The cost of new stock required to produce the weldment is fixed by the supplier. It is often possible to help control these costs by getting bids

from several suppliers and combining as many jobs as possible to get any discount for larger quantities purchased.

- *Scrap cost:* Scrap is an inevitable part of any project. It costs a company in two ways: by wasting expensive resources and by requiring cleanup and removal. Reducing scrap production through proper planning will result in a direct saving for any project.
- *Process cost:* The major welding processes—SMAW, GMAW, and FCAW—differ widely in their cost of equipment, operating supplies, and production efficiency. SMAW has the lowest initial cost and has excellent flexibility but also a higher total cost for large jobs.
- *Filler metal:* The cost of filler metal per pound is only a small part of its actual cost. The major welding processes (SMAW, GMAW, FCAW, and GTAW) have widely varying deposition and efficiency rates.
- *Labor cost:* Total labor cost includes wages and benefits. Insurance, sick leave, vacation, social security, retirement, and other benefits can range from 25% to 75% of the total labor cost. Because labor costs are figured on an hourly basis, they can be controlled only by increasing productivity.
- *Overhead costs:* Overhead costs are often intangible costs related to doing business. These costs include building rent or mortgage, advertising, insurance, utilities, taxes, licenses, governmental fees, accounting, loan payments, and property upkeep.
- *Finishing cost:* Postwelding cleanup, grinding, painting, or other finishing adds to the weldment's final production cost. Many of these finishing processes can produce some level of health hazard, and a major concern to everyone is the environment. Complying with local, state, and federal environmental laws can add significantly to the cost of painting, dipping, and plating. New environmentally friendly paints, low-pressure spray guns, and water-based products are a few of the advancements in finishing that have helped reduce environmental compliance costs.

JOINT DESIGN

Joint design is an important consideration when estimating weld cost. The root opening, root face thickness, and bevel angles must be studied carefully when making design decisions. All these factors affect the weld dimensions, **Figure 20-27**, which in turn determine the amount of weld metal needed to fill the joint. Plate thickness is a major factor that, in most cases, cannot be changed. Increasing the root opening increases cost. But larger root openings often allow the bevel angle to be reduced while maintaining good access to the weld root.

Controlling Cost To keep welding costs down, the joints should have the smallest possible root opening and the smallest reasonable bevel angle. These conditions are more easily achievable with welding processes that provide deep penetration. The other benefit of deep penetration is the option of a deeper root face and its significant effect on the volume of filler metal needed. In addition, the amount of reinforcement affects welding costs. Some reinforcement is unavoidable to ensure a full-thickness weld. However, too much reinforcement requires extra time and material, which can reduce the weld's strength and fatigue life.

Weld Size The weld should be approximately the same size as the metal is thick. Welds that are undersized or oversized can cause joint failure. Welds that are undersized do not have enough area to hold the parts under load. Welds that are oversized can make the joint too stiff. The lack of flexibility of the weld causes the metal near the joint to be highly stressed, **Figure 20-28**. The same will happen to a piece of wire bent between two pliers: it will break. But a piece of wire bent between your fingers will withstand more bending before it breaks.

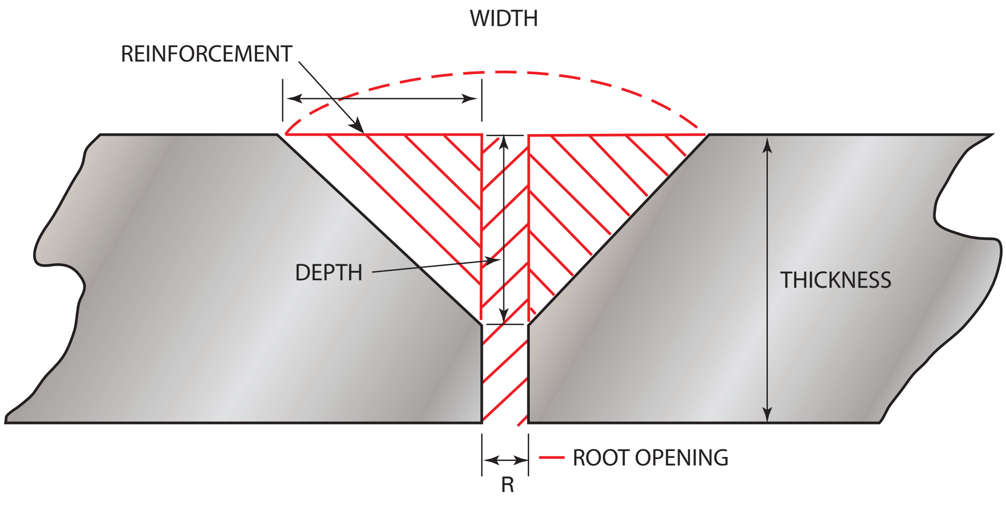


FIGURE 20-27 Calculation of weld requirements depending on joint design.

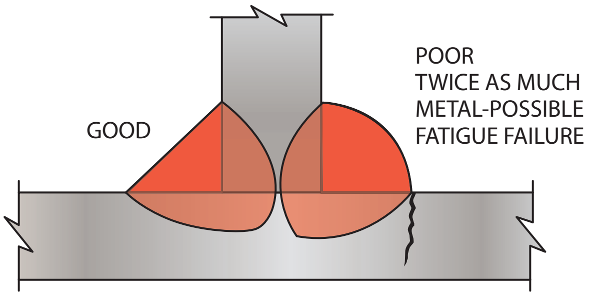


FIGURE 20-28 Overwelding can be harmful as well as costly.

Welds made on parts of unequal size should allow enough joint flexibility to prevent a crack from forming along the edge of the weld. It is possible to taper the thicker metal to reduce the thickness or to build up the thinner metal.

Overwelding Overwelding also contributes to welding costs. Welders often believe "if a little is good, a lot is better, and too much is just right." Too often it is assumed that a large reinforcement means greater strength, but that is never true.

Cutting weld volume also reduces the labor cost. It should be remembered that the labor content of welds almost always exceeds the cost of the expendable. Reducing the amount of filler metal needed also cuts the time needed to make the welds. This significant effect on labor costs, **Figure 20-29**, justifies the price of more expensive filler metals or welding processes. This assumes that the metals and processes provide enough increase either in penetration, to allow joint designs requiring less filler metal, or in deposition rates, to reduce welding times.

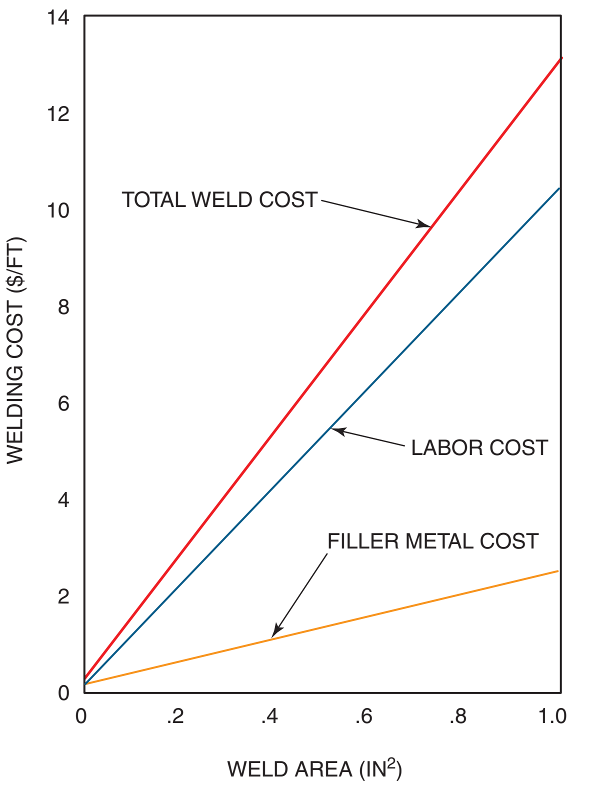


FIGURE 20-29 Increasing the weld size increases cost. Note the labor is 80% of the total cost (based on typical modern welding rates and efficiencies).

Groove Welds

For groove welds the bevel angle greatly affects the filler metal volume. As the groove angle increases, a larger volume of filler metal is required to fill it during welding. Because the volume is in proportion to the angle, the wider the angle, the greater the volume. Knowing the bevel angle, the filler metal volume can be calculated.

The first thing in determining the filler metal volume required during welding is to find the cross-sectional area of the weld groove. The cross-sectional area is equal to one-half of the root opening times the bevel depth. Use the following formula to find the cross-sectional area of the weld:

Formula 20-1

$$CS_{weld} = \frac{RO \times BD}{2}$$

Where:

CS_{weld} = cross-sectional area of the weld
RO = root opening
BD = bead depth

Some large grooved joints have a root opening that will require a substantial volume of filler metal. To determine the volume of filler metal required for this part of the weld, you must first find the cross-sectional area of the root opening. The cross-sectional area of the root opening is equal to the plate thickness times the root gap. Use the following formula to find the cross-sectional area of the root:

Formula 20-2

$$CS_{root} = PT \times RG$$

Where:

CS_{root} = cross-sectional area of the root opening
PT = plate thickness
RG = root gap

Cross-Sectional Area The total cross-sectional area of the weld in Figure 20-27 is the sum of the cross-sectional area of the weld plus the cross-sectional area of the root opening. Use the following formula to find the total cross-sectional area of the weld:

Formula 20-3

$$TCS = CS_{weld} + CS_{root}$$

Where:
TCS = total cross-sectional area
CS_{weld} = cross-sectional area of the weld
CS_{root} = cross-sectional area of the root opening

The total groove volume is then determined by multiplying the total cross-sectional area of the groove by the

weld length. Use the following formula to find the total groove volume of the weld:

Formula 20-4

$$GV = TCS \times WL$$

Where:

GV = groove volume
TCS = total cross-sectional area
WL = weld length

PRACTICE 20-3

Finding Weld Groove Volume

Using a pencil, paper, and calculator, determine the total volume of the following groove welds, **Figure 20-30**.

1. V-groove joint with the following dimensions:
   Width, 3/8 in.
   Depth, 3/8 in.
   Root opening, 1/8 in.
   Thickness, 1/2 in.
   Weld length, 144 in.
   Bevel joint with the following dimensions:
   Width, 0.25 in.
   Depth, 0.375 in.
   Root opening, 0.062 in.
   Thickness, 0.5 in.
   Weld length, 96 in.

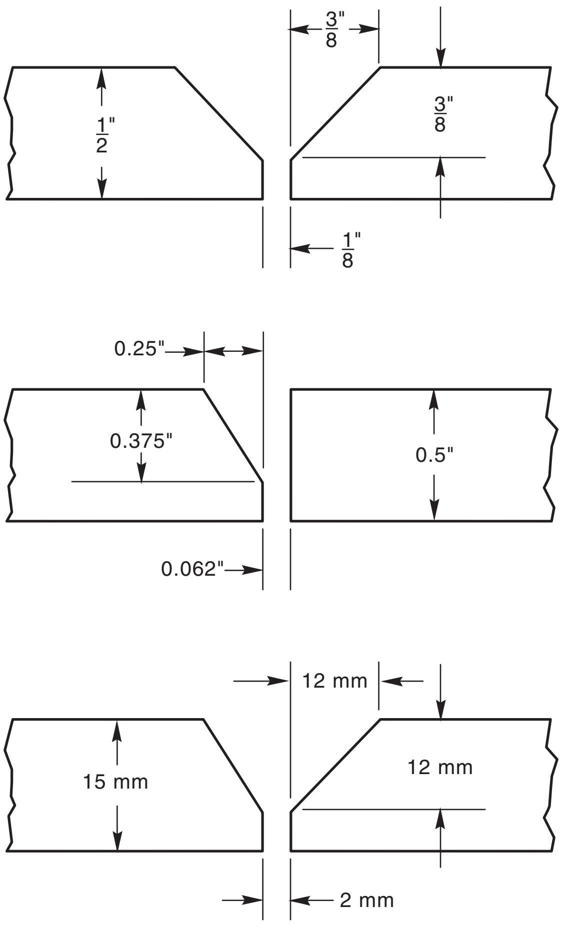


FIGURE 20-30 Practice 20-3. Find the weld groove volume.

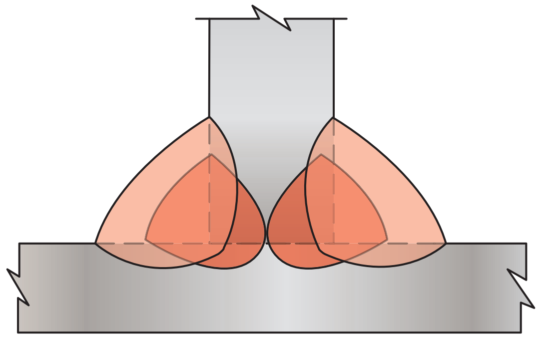


FIGURE 20-31 The red 1/4-in. (6-mm) fillet weld is stronger than the other fillet weld and contains approximately one-half the amount of filler metal.

2. V-groove joint with the following dimensions:
   Width, 12 mm
   Depth, 12 mm
   Root opening, 2 mm
   Thickness, 15 mm
   Weld length, 3600 mm

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

Fillet Welds

The deep penetration processes of fillet welds offer lower costs and improved weld quality. Smaller fillet welds with deeper penetration also have the potential for yielding much stronger welds, **Figure 20-31**. The cross-sectional area of a fillet weld is equal to one-half of the weld leg height times the weld leg width:

Formula 20-5

$$CS_{weld} = \frac{LH \times LW}{2}$$

Where:

CS_{weld} = cross-sectional area of the weld
LH = weld leg height
LW = weld leg width

The fillet weld volume is determined in the same manner as the groove weld by multiplying the area times the length:

Formula 20-6

$$GV = CS_{weld} \times WL$$

Where:

GV = groove volume
CS_{weld} = cross-sectional area of the weld
WL = weld length

WELD METAL COST

In their technical data sheets, manufacturers of filler metal provide information regarding the welding metal. The number of electrodes per pound or the length of wire per pound can be used to determine the pounds of electrodes needed to produce a weld. To make this determination, the

Material	Weight, lb/in.^{3}	Weight, g/cm^3
Aluminum	0.096	2.73
Steel	0.287	7.945

TABLE 20-7 Density of Metals

weight of weld metal required to fill the groove or make the fillet weld must be determined. The weight of weld metal is determined by multiplying the weld volume times the density of the metal, **Table 20-7**:

Formula 20-7

$$Wt_{\text{weld metal}} = GV \times MD$$

Where:

$Wt_{\text{weld metal}}$ = weight of weld metal
GV = groove volume
MD = metal density (weight of metal in pounds per cubic inch)

PRACTICE 20-4

Finding Weld Weight of Filler Metal

Using a pencil, paper, and a calculator, determine the weight of metal required for each of the welds described in Practice 20-3. Calculate the weight for both steel and aluminum base and filler metals. Using the weight of weld metal deposited allows for better comparisons when a number of different welds are being made. The weight of weld metal either can be determined for the welding prints or measured as the welder uses up supplies, **Figure 20-32.**

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

COST OF ELECTRODES, WIRES, GASES, AND FLUX

To estimate the cost of electrodes, wire, gases, and flux, you must obtain the current cost per pound of electrode or welding wire plus the cost of shielding gas and flux from a supplier or from the Internet. To determine how much shielding gas will be used, you must know the flow rate. Shielding gas flow rates vary slightly with the kind of gas used. The flow rates in **Table 20-8** are average values whether the shielding gas is an argon mixture or pure CO_2. Use these rates in your calculations if the actual flow rate is not available.

In the submerged arc process (SAW), the ratio of flux to wire consumed in the weld is approximately 1 to 1 by weight. When the loss, which is due to flux handling and flux recovery systems, is considered, the average ratio of flux to wire is approximately 1.4 pounds of flux for each pound of wire consumed. If the actual flux-to-wire ratio is unknown, use 1.4 for cost estimating.

Deposition Efficiency

Not every pound of electrode filler metal purchased is converted into weld metal. Some portion of every electrode is lost

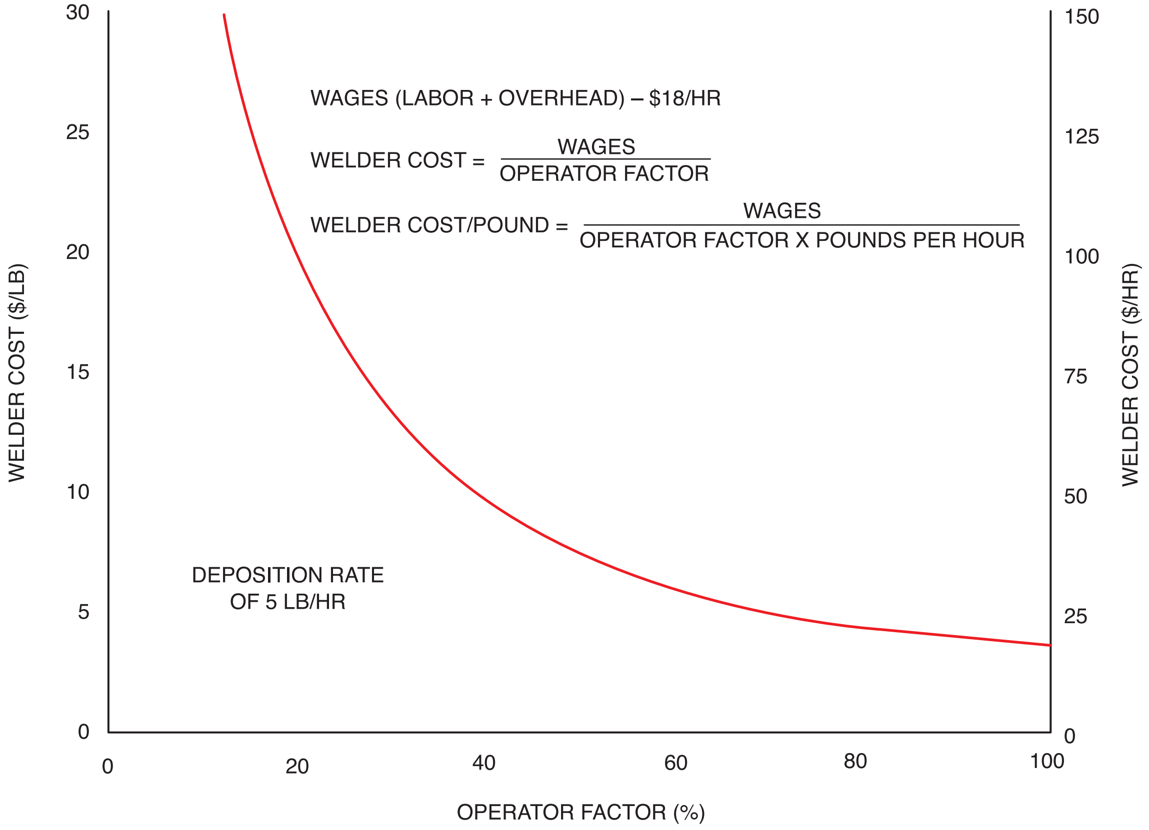


FIGURE 20-32 Low operator factors are costly.

	GMAW		FCAW		
Wire diameter	.035″	.045″ – 1/16″	.045″	1/16″	5/64″ – 1/8″
CFH	30	35	35	40	45

TABLE 20-8 Approximate Shielding Gas Flow Rate Cubic Feet Per Hour

as slag, spatter, and/or fume. Some, such as SMAW electrode stub ends, are unused. The amount of raw electrode deposited as weld metal is measured as deposition efficiency. If all is deposited, then the deposition efficiency is 100%. If half is lost, then the deposition efficiency is 50%. The argon-shielded GMA process is approximately 95% efficient. The SMAW process is between 40% and 60% efficient, depending on the electrode and the welder using it. Thus, a relatively costly filler metal with high efficiency can be as cost-effective as one that appears to be cheaper, **Figure 20-33**. The efficiency can then be calculated by the following formula:

Formula 20-8

$$DE = \frac{Wt_{\text{weld metal}}}{Wt_{\text{electrode used}}} \text{ or } DE = \frac{DR}{BOR}$$

Where:

DE = deposition efficiency
$Wt_{\text{weld metal}}$ = weight of weld metal
$Wt_{\text{electrode used}}$ = weight of electrode used
DR = deposition rate in pounds per hour
BOR = burn-off rate in pounds per hour

The deposition efficiency tells us how many pounds of weld metal can be produced from a given weight of the electrode of welding wire. As an example, 100 lb of a flux cored electrode with an efficiency of 85% will produce approximately 85 lb of weld metal. One hundred pounds of coated electrode with an efficiency of 65% will produce approximately 65 lb of weld metal less the weight of the stubs discarded. Note that electrodes priced at $0.65 actually cost approximately $1.30 per pound as weld metal because approximately 50% is wasted. The more expensive GMA wire at $0.85 costs approximately $0.90 per pound as weld metal when deposited because only 5% is lost as spatter and fume. Even with the added $0.15 for shield gas, the final cost of $1.05 is less than that of welds made with covered electrodes.

Deposition Rate

The deposition rate is the rate at which weld metal can be deposited by a given electrode or welding wire, expressed in pounds per hour. It is based on continuous operation, with no time allowed for stops and starts for inserting a new electrode, cleaning slag, terminating the weld, or other reasons. The deposition rate will increase as the welding current is increased. When using solid or flux cored wires, the deposition rate will increase as the electrical stickout is increased and the same welding current is maintained. True deposition rates for each welding filler metal, whether it is a coated electrode or a solid or flux cored wire, can only be established by an actual test. The weldment is weighed before and after welding as the whole process is timed. **Table 20-9**, **Table 20-10**, and **Table 20-11A** and **B** contain average values for the deposition rate of the various welding filler metals based on welding laboratory tests and published data.

Deposition Data Tables

The deposition efficiency of a welding process refers to the percentage of the welding filler material that actually becomes part of the weld deposit. Some welding processes, such as SMAW, lose part of the filler material as the result of weld spatter, whereas others, such as GTAW, do not. Even within a single process the deposition efficiencies can

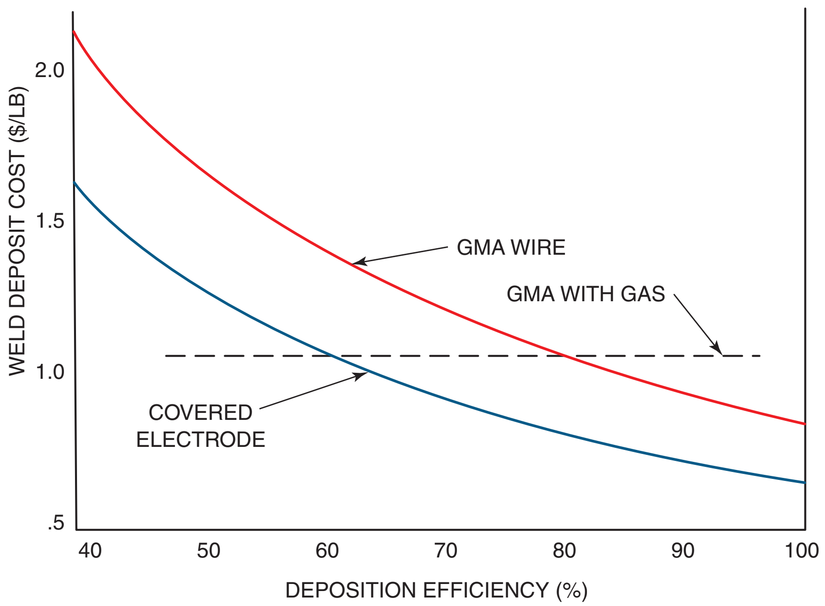


FIGURE 20-33 Weld metal cost is affected by the process deposition efficiency.

E6010			
Electrode Diameter	Amperes	Deposition Rate, lb/hr	Efficiency %
1/8	100	2.1	76.3
	130	2.3	68.8
5/32	140	2.8	73.6
	170	2.9	64.1
3/16	160	3.3	74.9
	190	3.5	69.7
7/32	190	4.5	76.9
	230	5.1	73.1
1/4	220	5.9	77.9
	260	6.2	76.2

E6011			
Electrode Diameter	Amperes	Deposition Rate, lb/hr	Efficiency %
1/8	120	2.3	70.7
5/32	150	3.7	77.0
3/16	180	4.1	73.4
7/32	210	5.0	74.2
1/4	250	5.6	71.9

E6012			
Electrode Diameter	Amperes	Deposition Rate, lb/hr	Efficiency %
1/8	130	2.9	81.8
5/32	165	3.2	78.8
	200	3.4	69.0
3/16	220	4.0	77.0
	250	4.2	74.5
7/32	320	5.6	69.8
1/4	320	5.6	70.0
	360	6.6	67.7
	380	7.1	66.0
5/16	400	8.1	70.2

E6013			
Electrode Diameter	Amperes	Deposition Rate, lb/hr	Efficiency %
5/32	140	2.6	75.6
	160	3.0	74.1
	180	3.5	71.2
3/16	180	3.2	73.9
	200	3.8	71.1
	220	4.1	72.9
7/32	250	5.3	71.3
	270	5.7	73.0
	290	6.1	72.7
1/4	290	6.2	75.0
	310	6.5	73.5
	330	7.1	72.1
5/16	360	8.6	70.7
	390	9.4	71.8
	450	10.3	71.3

E7014			
Electrode Diameter	Amperes	Deposition Rate, lb/hr	Efficiency %
1/8	120	2.4	63.9
	150	3.1	61.1
5/32	160	3.0	71.9
	200	3.7	67.0
3/16	230	4.5	70.9
	270	5.5	73.2
7/32	290	5.8	67.2
	330	7.1	70.3
1/4	350	7.1	68.7
	400	8.7	69.9
5/16	440	8.9	62.2
	500	11.1	65.4

TABLE 20-9 Deposition Data

change depending on the electrode classification used. Deposition data tables provide an average percentage of weld deposit efficiencies for each welding process.

Coated Electrodes

The deposition efficiency of coated electrodes does not subtract the unused electrode stub that is discarded. This is understandable because the stub length can vary with the operator and the application. Long, continuous welds are usually conducive to short stubs, whereas on short intermittent welds the stub length tends to be longer. **Figure 20-34** illustrates how the stub loss influences the electrode efficiency when using coated electrodes. In **Figure 20-35**, a 14-in.-long, 5/32-in. diameter E7018 electrode at 140 amperes is considered. It is 75% efficient and a 2-in. stub loss is assumed. The 75% efficiency applies only to the 12 in. of the electrode consumed in making the weld, not to the 2-in. stub. When the 2-in. stub loss and the 25% lost to slag, spatter, and fumes are considered, the efficiency minus stub loss is lowered to 64.3%. This means that for each 100 lb of electrodes, you can expect an actual deposit of approximately 64.3 lb of weld metal if all electrodes are used to a 2-in. stub length.

The formula for efficiency including stub loss is important. It must always be used when estimating the cost of depositing weld metal by the SMAW method. The formula used to establish the efficiency of coated electrodes including stub loss is based on the electrode length and is slightly inaccurate. That is, it does not consider that electrode weight is not evenly distributed because of flux removed from the electrode holder end (indicated by the dotted lines in Figure 20-34). Use of the formula will result in a 1.5% to 2.3% error that varies with electrode size, coating thickness, and stub length. However, the formula is acceptable for estimating purposes.

To find the percentage of the weld deposition efficiency for the values given in Figure 20-29, the formula is as follows:

Formula 20-9

$$\%DE = \left[\frac{(EL - SL) \times DE}{EL}\right] \times 100$$

E7016			
Electrode Diameter, in.	Amperes	Deposition Rate, lb/hr	Efficiency %
5/32	140	3.0	70.5
	160	3.2	69.1
	190	3.6	66.0
3/16	175	3.8	71.0
	200	4.2	71.0
	225	4.4	70.0
	250	4.8	65.8
1/4	250	5.9	74.5
	275	6.4	74.1
	300	6.8	73.2
	350	7.6	71.5
5/16	325	8.0	77.3
	375	9.0	76.3
	425	10.2	76.7

E7024			
Electrode Diameter, in.	Amperes	Deposition Rate, lb/hr	Efficiency %
1/8	140	4.2	71.8
	180	5.1	70.7
5/32	180	5.3	71.3
	210	6.3	72.5
	240	7.2	69.4
3/16	245	7.5	69.2
	270	8.3	70.5
	290	9.1	68.0
7/32	320	9.4	72.4
	360	11.6	69.1
1/4	400	12.6	71.7

Low Alloy, Iron Powder Electrodes of the Types E7018, E8018, E9018, E10018, E11018, and E12018			
Electrode Diameter, in.	Amperes	Deposition Rate, lb/hr	Efficiency %
3/32	70	1.37	70.5
	90	1.65	66.3
	110	1.73	64.4
1/8	120	2.58	71.6
	140	2.74	70.9
	160	2.99	68.1
5/32	140	3.11	75.0
	170	3.78	73.5
	200	4.31	73.0
3/16	200	4.85	76.4
	250	5.36	74.6
	300	5.61	70.3
7/32	250	6.50	75.0
	300	7.20	74.0
	350	7.40	73.0
1/4	300	7.72	78.0
	350	8.67	77.0
	400	9.04	74.0

TABLE 20-10 Deposition Data

Where:

%DE = percentage of weld deposition efficiency
EL = electrode length
SL = stub loss
DE = deposit efficiency

$$\%DE = \left[\frac{(EL - S) \times DE}{EL}\right] \times 100$$

$$\%DE = \left[\frac{(14 - 2) \times 0.75}{14}\right] \times 100$$

$$\%DE = \left[\frac{12 \times 0.75}{14}\right] \times 100$$

$$\%DE = \left[\frac{9}{14}\right] \times 100$$

$$\%DE = 0.6429 \times 100$$

$$\%DE = 64.29\%$$

In this example, the electrode length is known, the stub loss must be estimated, and the efficiency is taken from Table 20-9 and Table 20-10. Use an average stub loss and 3 in. for coated electrodes if the actual shop practices concerning stub loss are not known.

Efficiency of Flux Cored Wires

Flux cored wires have a lower-power flux-to-metal ratio than coated electrodes and, therefore, a higher deposition efficiency. Stub loss need not be considered because the wire is continuous. The gas shielded wires of the E70T-1 and E70T-2 types have efficiencies of 83% to 88%. The gas shielded basic slag wire (E70T-5) is 85% to 90% efficient with CO_2 as the shielded gas. The efficiency can reach 92% when a 75% argon and 25% CO_2 gas mixture is used. Use the efficiency figures in Table 20-11A for your calculations if the actual values are not known. The efficiency of self-shielded flux cored wires has more variation because of the large assortment of available types designed for specific applications. The efficiency of the high-deposition, general purpose type, such as E70T-4, is 81% to 86%, depending on wire size and electrical stickout. The chart in Table 20-11A shows the optimum conditions for each wire size and may be used in your calculations.

Efficiency of Solid Wire for GMAW

The efficiency of solid wires in GMAW is very high and will vary with the shielding gas or gas mixture used, Table 20-11B. Using CO_2 will produce the most spatter, and the average efficiency will be approximately 93%. Using a 75% argon and 25% CO_2 gas mixture will result in somewhat less spatter and an efficiency of approximately 96%. A 98% argon and 2% oxygen mixture will produce even less spatter and the average efficiency will be approximately 98%. Stub loss need not be considered because the wire is continuous. **Table 20-12** shows the average efficiencies to use in your calculations if the actual efficiency is not known.

Flux Cored Electrodes—Gas Shielded Types E70T-1, E71T-1, E70T-2, and All Low Alloy Types			
Electrode Diameter, in.	Amperes	Deposition Rate, lb/hr	Efficiency %
0.45	180	5.3	85.0
	200	5.5	86.0
	240	6.9	84.0
	280	13.0	83.0
0.52	190	4.8	85.0
	210	5.3	83.5
	270	7.6	83.0
	300	9.8	85.0
1/16	200	5.2	85.0
	275	10.1	85.0
	300	11.5	85.0
	350	13.3	86.0
5/64	250	6.4	85.0
	350	10.5	85.0
	450	14.8	85.0
3/32	400	12.7	85.0
	450	15.0	86.0
	500	18.5	86.0
7/64	550	17.1	85.0
	625	19.6	86.0
	700	23.0	86.0
1/8	600	16.2	86.0
	725	22.5	86.0
	850	29.2	85.0

Flux Cored Electrodes—Self-Shielded			
Type and Diameter, in.	Amperes	Deposition Rate, lb/hr	Efficiency %
E70T-3			
3/32	450	14.0	88
E70T-4			
3/32	400	18.0	85
.120	450	20.0	81
E70T-6			
5/64	350	11.9	86
3/32	480	14.7	81
E70T-7			
3/32	325	11.4	80
7/64	450	18.0	86
E71T-7			
.068	200	4.2	76
5/64	300	8.0	84
E71T-8			
5/64	220	4.4	77
3/32	300	6.7	77
EG1T8-K6			
5/64	235	4.3	76
E71T8-Ni1			
5/64	235	4.3	77
3/32	345	8.2	84
E70T-10			
3/32	400	13.0	69
E71T-11			
5/64	240	4.5	87
3/32	250	5.0	91
E70T4-K2			
3/32	300	14.0	83

NOTE: Values shown are optimum for each type and size.

TABLE 20-11a Deposition Data

Efficiency of Solid Wires for SAW

In submerged arc welding there is no spatter loss, and an efficiency of 99% may be assumed. The only loss during welding is the short piece that the operator must clip off the end of the wire to remove the fused flux that forms at the termination of each weld. This is done to ensure a good start on the next weld.

Operating Factor

Operating factor is the percentage of a welder's working day actually spent on welding. It is the arc time in hours divided by the total hours worked. A 45% (0.45) operating factor means that only 45% of the welder's day is actually spent on welding. The rest of this time is spent installing a new electrode or wire, cleaning slag, positioning the weldment, cleaning spatter from the welding gun, and so on.

When using coated electrodes (SMAW), the operating factor can range from 15% to 40% depending on material handling, fixturing, and operator dexterity. If the actual operating factor is not known, then an average of 30% may be used for cost estimates involving the shielded metal arc welding process.

When welding with solid wires (GMAW) using the semiautomatic method, operating factors ranging from 45% to 55% are easily attainable. For cost-estimating purposes, use a 45% operating factor. The estimated operating factor of FCAW is approximately 5% lower than that of GMAW to allow for slag removal time.

In semiautomatic submerged arc welding, slag removal and loose flux handling must be considered. A 40% operating factor is typical for this process.

Automatic welding using the GMAW, FCAW, and SAW processes requires each application to be studied individually. Operating factors ranging from 50% to 100% may be obtained depending on the degree of automation.

Manual GTAW has the lowest operating factor of all the arc welding processes. It ranges from a low of 10% to a high of 40%. The lower operating factor most often results from piecework where every weld is different. The higher operating factors are associated with production welding jobs where the welds are often exactly the same. The average GTA welding factor for nonproduction jobs is approximately 15%.

Table 20-13 shows average operating factor values for the various welding processes. These figures may be used for cost estimating when the actual operating factor is not known.

Gas Metal Arc Welding Solid Wires			
Diameter, in.	Amperes	Melt-Off Rate, lb/h	Efficiency, % (See Note)
.030	75	2.0	
	100	2.7	
	150	4.2	
	200	7.0	
.035	80	3.2	
	100	2.8	
	150	4.3	
	200	6.3	
	250	9.2	
.045	100	2.1	
	125	2.9	
	150	3.7	
	200	5.7	
	250	7.4	
	300	10.4	
	350	13.5	
1/16	250	6.7	
	275	8.6	
	300	9.2	
	350	11.5	
	400	14.3	
	450	17.8	

Submerged Arc Welding (Values for 1″ Stickout)			
Diameter, in.	Amperes	Melt-Off Rate, lb/hr	Efficiency %
5/64	300	7.0	Assume
	400	10.2	99%
	500	15.0	Efficiency
3/32	400	9.4	Assume
	500	13.0	99%
	600	17.2	Efficiency
1/8	400	8.5	Assume
	500	11.5	99%
	600	15.0	Efficiency
	700	19.0	
5/32	500	11.3	Assume
	600	14.6	99%
	700	18.4	Efficiency
	800	22.0	
	900	26.1	
3/16	600	13.9	Assume
	700	17.5	99%
	800	21.0	Efficiency
	900	25.0	
	1,000	29.2	
	1,100	34.0	

NOTE: Efficiencies for GMAW with the following shielding gases:
98% efficient with 98% Ar and 2% O_2
98% efficient with 75% Ar and 25% CO_2
93% efficient with straight CO_2

TABLE 20-11b Deposition Data

ER70S-X and ER3XX				
Filler Diameter	Electrode Diameter	Amperes	Deposition Rate, lb/hr	Efficiency %
1/16	1/16	75	0.75	99
3/32	3/32	110	1.7	99
1/8	1/8	125	3	99

ER4043				
Filler Diameter	Electrode Diameter	Amperes	Deposition Rate, lb/hr	Efficiency %
1/16	1/16	70	0.3	99
3/32	3/32	90	0.6	99
1/8	1/8	100	1	99

TABLE 20-11c Deposition Data

Knowing the productivity of welders is necessary when determining the cost of the finished part. In some shops, this cost is passed directly to the customer in the form of cost plus. It may also be used to determine at what level the shop can bid on new work and still make a profit. It is not often used to promote or penalize welders.

The number of parts produced is useful if there are a number of welders making the same or similar parts in a production shop. A comparison of the productivity can be made because there should be little difference in the average time compared with each welder's actual time.

The length of weld produced is a useful tool when a lot of the same welding is required. Welding on items like ships, tanks, or large vessels may take weeks, months, or years. The length that a welder produces in this type of production can be recorded on a regular basis. The deposition rates of the process also affect costs. Processes with high deposition rates can be very cost-effective, **Figure 20-36**. A compelling reason for replacing covered electrodes with small diameter cored wires is that the deposition rates in the vertical position can be increased from approximately 2 lb per hour to more than 5 lb per hour. Thus, the welder cost in this example decreases from more than $30 per pound to approximately $12 per pound of weld metal deposited.

Because operating factors and deposition rates interact strongly, their effects on weld costs are examined together. The time spent preparing and positioning weld joints for submerged arc welding is costly, but that process's high deposition rates justify the time, Figure 20-36. Covered electrodes, however, cannot compete with most other processes unless the setup time and other factors can be reduced. The speed with which alloys and electrode types can be changed explains why covered electrodes have remained competitive in small job shops, especially when typical welds are quite short. Changeover times with GMA processes can be lengthy. If the welding jobs are small, then the operator factor can drop below

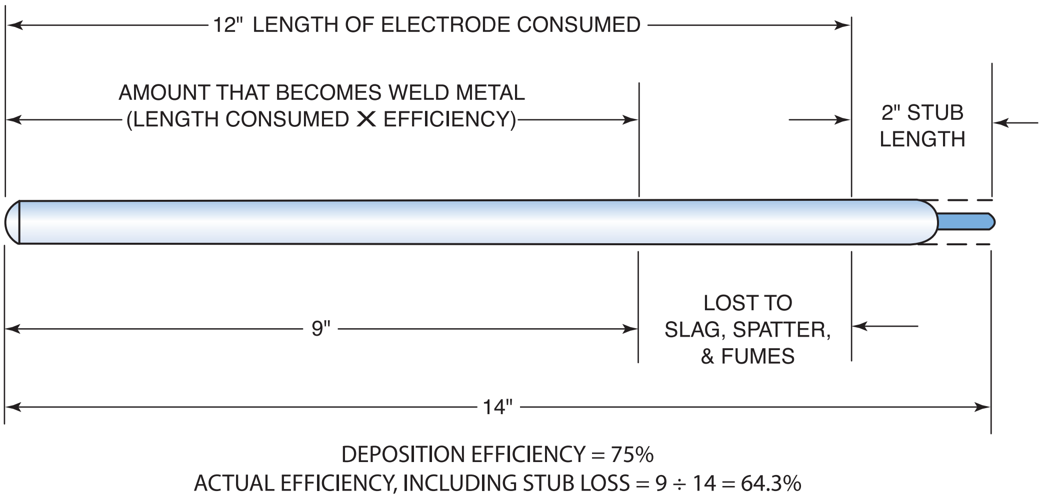


FIGURE 20-34 Deposition efficiency and stub loss.

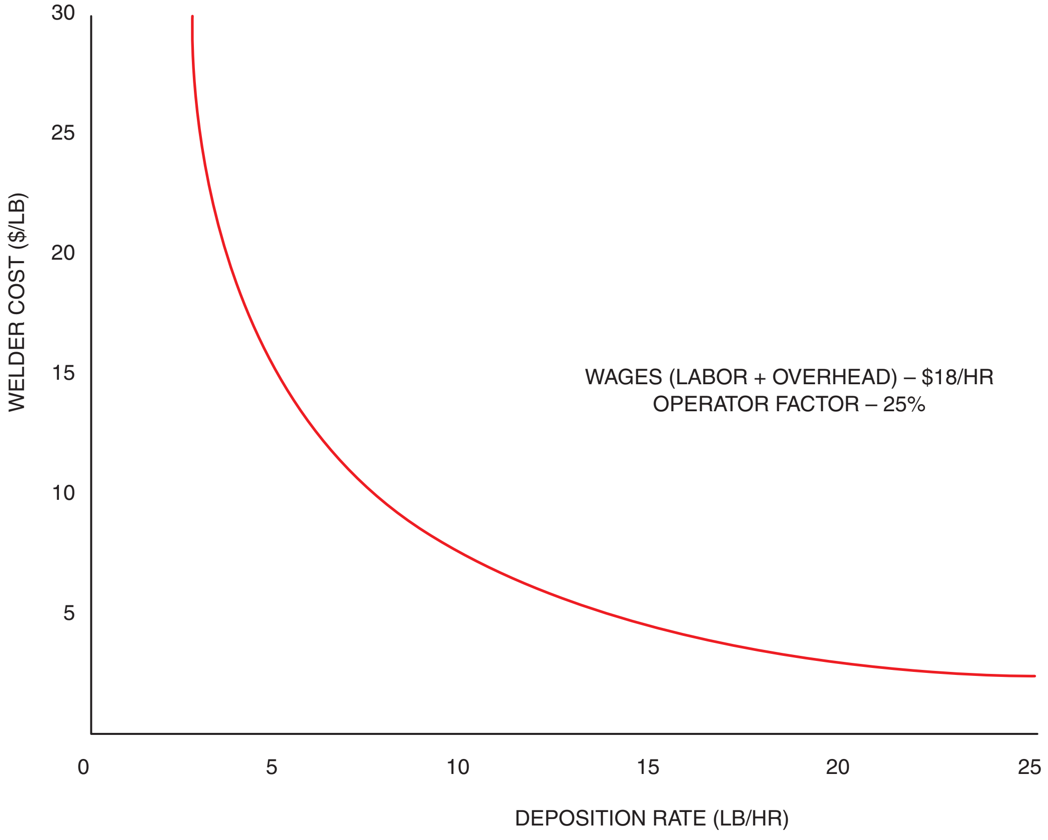


FIGURE 20-35 High deposition rates are desirable.

Shielding Gas	Efficiency Range	Average Efficiency
Pure CO_2	88% to 95%	93%
75% A–25% CO_2	94% to 98%	96%
98% A–2% O_2	97% to 98.5%	98%

TABLE 20-12 Deposition Efficiencies: Gas Metal Arc Welding Carbon and Low-Alloy Steel Wires

Welding Process			
SMAW	GMAW	FCAW	SAW
30%	50%	45%	40%

TABLE 20-13 Approximate Operating Factor

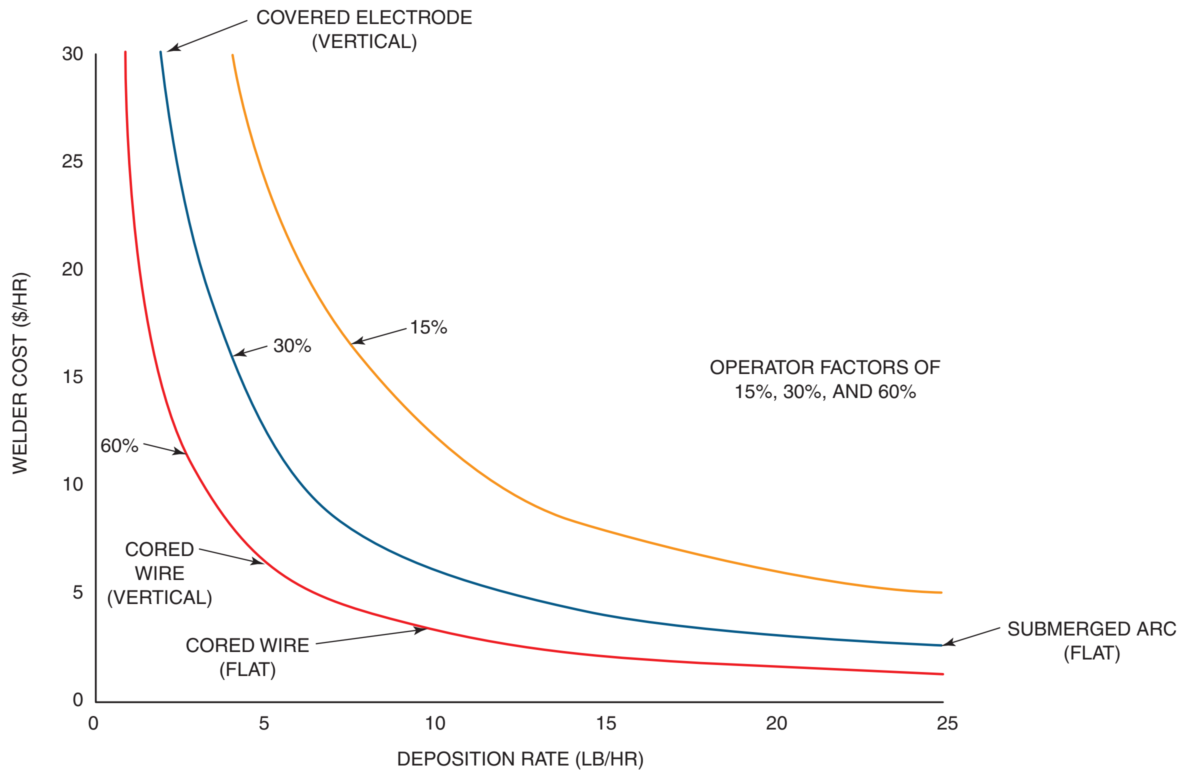


FIGURE 20-36 Newer processes can reduce welder costs.

15%. Excessively high deposition rates may be needed to compensate for that deficit.

Labor and Overhead

Labor and overhead may be considered jointly in your calculations. Labor is the welder's hourly rate of pay including wages and benefits. Overhead includes allocated portions of plant operating and maintenance costs. Weld shops in manufacturing plants normally have established labor and overhead rates for each department. Labor and overhead rates can vary greatly from plant to plant and with location. **Table 20-14** shows how labor and overhead can vary and suggests an average value to use in your calculations when the actual value is unknown.

Cost of Power

Cost of electrical power is a very small part of the cost of depositing weld metal and in most cases is less than 1% of the total. It will be necessary for you to know the power cost expressed in dollars per kilowatt hour ($/kWh) if required for a total cost estimate.

Small shops	$27.50 to $45.00
Large shops	$47.00 to $96.00
Average	$54.00

TABLE 20-14 Approximate Labor and Overhead Rates

Other Useful Formulas

The following formulas will assist you in making other useful calculations.

For Formula 20-9, use the values from Example 20-1 to find the total weld metal weight. Formula 20-10 is used to find the number of hours required to complete the work.

Formula 20-10

$$TWt_{\text{total weld metal}} = \frac{Wt_{\text{weld metal}} \times WL}{DF}$$

$$TWt_{\text{total weld metal}} = \frac{0.814 \times 1280}{0.639}$$

$$TWt_{\text{total weld metal}} = 1631 \text{ lbs}$$

Formula 20-11

$$W_{\text{time}} = \frac{Wt_{\text{weld metal}} \times WL}{DR \times OF}$$

$$W_{\text{time}} = \frac{0.814 \times 1280}{5.36 \times 0.30}$$

$$W_{\text{time}} = \frac{1042}{1608}$$

$$W_{\text{time}} = 648 \text{ hrs}$$

Use Formula 20-11 to find the number of hours required to make the same 1631 lb of weld if GMAW, FCAW, GTAW, and SAW are used.

- GMAW equipment setup is 0.30-in. diameter wire at 100 amperes.
- FCAW equipment setup is 0.45-in. diameter E70T-1 at 180 amperes.
- GTAW equipment setup is 1/8-in tungsten and 1/8-in. ER70S at 125 amperes.
- SAW equipment setup is 1/8-in. diameter wire at 400 amperes.

Refer to Table 20-10 and Table 20-13 for the necessary data.

BILL OF MATERIALS

A Bill of Materials is a list of the materials, supplies, and consumables required to fabricate a project for a customer. Each item would appear on a separate line, **Figure 20-37**. The term **shop time** is usually used to indicate an estimate of the time required for the fabrication; it may also be used on an invoice.

BILL OF MATERIALS				
Name:		Practice Number:	Date:	
Instructor:		Project Description:	Class:	
Item	Quantity	Base Metal Type and Dimensions	Unit Price	Item Cost
1				
2				
3				
4				
5				
6				
7				
8				
		Total Base Metal Cost		
Item	Quantity	Filler Metal Type and Cost		
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
		Total Filler Metal Cost		
		Total Material Cost		

FIGURE 20-37 Bill of Materials.

INVOICE

An invoice is a list of all of the items provided to a customer along with the total sum due. Invoices include all of the expenses involved in the production, delivery, taxes, and others. It is the statement provided to the customer with the expectation that they will pay you for the work performed.

PRACTICE 20-5

Create a Bill of Materials

Using a pencil, blank sheet of paper, copy of the "Bill of Materials" form listed in Appendix II or provided by your instructor, and a calculator, create a Bill of Materials for the weldments shown in **Figure 20-38**. Use **Table 20-15**

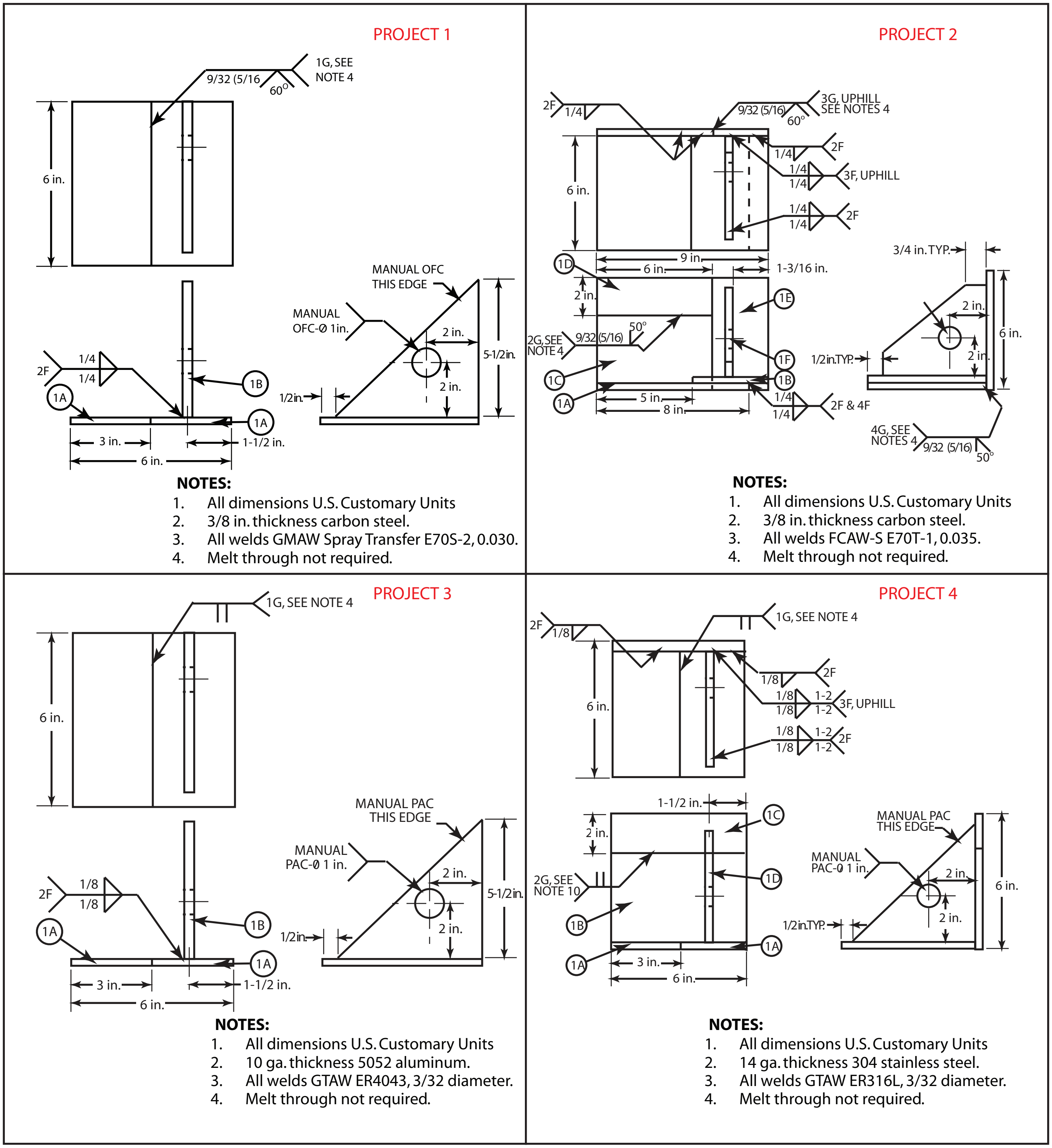


FIGURE 20-38 Practice 20-5. Create a Bill of Materials.

Material	Thickness	Cost per sq/in
304 Stainless Steel	10 Gauge	0.16
304 Stainless Steel	14 Gauge	0.07
Hot Rolled Steel	10 Gauge	0.06
Hot Rolled Steel	14 Gauge	0.02
5052 Aluminum	10 Gauge	0.06
5052 Aluminum	14 Gauge	0.03
Steel Plate	3/8-in.	0.08

TABLE 20-15 Cost of Materials per Square Inch

Filler Metal	Diameter, in.	Cost per Pound
ER70S-2	3/32	$3.96
ER70S-2	0.030	$3.95
E70T-1	0.035	$6.26
ER316L	3/32	$13.20
ER4043	3/32	$17.45

TABLE 20-16 Filler Metal Cost per Pound

and **Table 20-16** Cost of Materials per Square Inch and Table 20-16 Filler Metal Cost per Pound or prices of materials supplied by your instructor.

On a blank sheet of paper calculate the following for each of the weldments shown in Figure 20-38.

Step 1—Use the formula for area and a calculator to find the area of each of the individual items that comprise the workmanship sample, and show your work, **Figure 20-39**.

Step 2—Use the base metal cost in Table 20-15 to calculate the cost of each of the items.

Step 3—Use the length and size of each weld to calculate the volume of the weld metal required to make each weld.

Area
Item 1 6" x 6" = 36 sq in
Item 2 2" x 6" = 12 sq in
Total 48 sq in

Base Metal Cost
Item 1 36 in² x $0.07 = $2.52
Item 2 12 in² x $0.07 = $0.84
Total $3.36

FIGURE 20-39 Show your calculations used for the Bill of Materials.

Step 4—Use the weight of metals found in Table 20-7 to calculate the weight of the filler metal required to make each weld.

Step 5—Using the deposition efficiencies found in Table 20-9, Table 20-10, and Table 20-11, calculate the number of pounds of filler metal that must be purchased to produce a weld containing the required amount of filler as calculated in Step 4.

Step 6—Using the filler metal cost in Table 20-16, calculate the cost of each weld.

Step 7—Add each of the item's cost for base metal and filler metal.

Step 8—Transfer all of the information for each of the items onto the Bill of Materials, Figure 20-37.

Step 9—Repeat this process with each of the four workmanship samples in Figure 20-38.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

Summary

Math is a very important part of welding metal fabrication. You will often use your math skills as a welder fabricator to locate parts, lay out parts, calculate material needs, and determine cost. There is an old saying—measure twice, cut once. You never want to say, "I've cut it off twice, and it's still too short." Math is a skill, and like the skill of welding, it requires practice to become an expert. As you weld on projects, take every opportunity to practice your math. As you practice math, you will find shortcuts to some math problem-solving.

Once you have learned the mathematical processes, a calculator can be a big help. A word of caution about using a calculator: you should do a quick estimate of the answer you expect from a problem. That way, when you get an answer from the calculator, you can compare the two. Sometimes we hit the wrong key on a calculator by mistake so the answer is not even close to being correct. If it differs greatly, recheck your work.

Controlling the cost of a weldment can be as important as producing a quality welded product, because if you spend too much time in preparing and producing the weld to a quality standard far above that required by the industry, the end product may be excessively expensive and unmarketable. An example of a product requiring a relatively low level of welding skills is yard art. For these decorative or ornamental pieces, the customer is most frequently looking at cost. Welding on these items must merely hold them together to meet market demands. An example of a product requiring a high level of welding skills is the engines on rockets. All of these welds must be precise at any expense. Most welding requirements obviously fall somewhere between these two extremes. For both you and your company's benefit, you must learn to meet their needs and standards in the most cost-effective manner.

As you worked up the project cost in Practice 20-5, you can see that the stainless steel workmanship standard is significantly more expensive than that for the other three projects. For that reason, the AWS will allow students to take the stainless steel workmanship qualification test using mild steel base plates with stainless steel filler metal as a way to help schools control cost.

Review

1. What are two ways math is most commonly used in the welding shop?
2. What is the two-letter abbreviation for the metric system?
3. List factors that affect the cost of producing weldments.
4. List three examples of whole numbers.
5. List three examples of decimal fractions.
6. List three examples of a mixed unit.
7. List three examples of fractions.
8. Add the following angles:
   a. 30° 50' + 20° 5'
   b. 25° 25' + 62° 45'
9. Subtract the following angles:
   a. 45° 48' − 10° 20'
   b. 90° 5' − 3° 15'
10. Using the Pythagorean theorem, find "c" if "a" = 6 and "b" = 8.
11. Sketch a right triangle, equilateral triangle, and isosceles triangle.
12. Find the area of the following:
    a. Square that is 55″ wide
    b. Circle with a 22″ diameter
    c. Equilateral triangle with a 5″ base and 3″ height
    d. Oval that is 20″ wide and 11″ high
    e. Parallelogram with a 3′ base and 7′ height
13. Find the volume of the following:
    a. 5″ cube
    b. 10′ of 8″ pipe
14. What would the labor cost be if 20 hours were worked at an hourly rate of $25?
15. What is the first step in the sequence of mathematical operations?
16. If you need two pieces of pipe—one must be 15 ft and the other 10 ft—what is the total amount of pipe needed?
17. How many total feet of metal stock would you need if one piece is 12 ft 5 in. long and the other is 7 ft 3 in. long?
18. How many total feet of metal stock would you need if one piece is 11 ft 9 in. long and the other is 6 ft 5 in. long?
19. How many feet of scrap pipe will you have left from a 9 ft 6 in. piece when 4 ft 2 in. is cut off?
20. How much scrap pipe will you have once you cut out 5.5 ft from a 20-ft length of pipe?
21. When the denominators of two fractions to be added or subtracted are different, what must be done before they can be added?
22. How thick will the finished part be if two pieces of metal are welded together if one is 3/4 in. thick and the other is 5/16 in. thick?
23. How much metal is left if 1/8 in. is ground off a 5/16-in.-thick plate?
24. What is a dimensioning tolerance?
25. What is the minimum and maximum length a part can be if it is shown as needing to be 5 7/8 in. ± 1/8?
26. Give examples of welding applications where angles would be used.
27. Write the Pythagorean Theorem formula for a right triangle.
28. What is the name of a triangle where all three sides are the same length?
29. Why is it important to know the perimeter measurement of a weldment before cutting?
30. In what welding applications might you need to know the area of a part's surface?
31. List examples of fixed and variable costs that must be considered when estimating a job.
32. List examples of overhead costs that a welding shop might have.
33. When estimating weld cost, what weld joint design factors should be considered?
34. When a weld is oversized, what joint failure problem can result?
35. How does the bevel angle in a groove weld affect the filler metal volume?
36. What is the cross-sectional area of a V-groove weld that is 6 mm wide and 8 mm deep on a 10-mm-thick plate with a 2-mm root opening? What would the area be in square inches?
37. What is the cross-sectional area of a fillet weld that has an equal leg of 1/2 in.? What is the SI area?
38. What two amounts must be multiplied to determine the weight of weld metal required to fill a groove or make a fillet weld?
39. How many pounds of steel electrode are required to make a weld that has a volume of 18 in.^{3}?

40. Not every pound of electrode filler metal used is converted into weld metal. Why?

41. What does it mean if an electrode has a 50% deposition efficiency?

42. What is the meaning of the term *deposition rate*?

43. What factor is not included in the deposition efficiency of coated electrodes?

44. Why do flux cored wires have a higher deposition efficiency than coated electrodes?

45. If a welding project has a 45% operating factor, what does that mean?

Chapter 21

Reading Technical Drawings

OBJECTIVES

After completing this chapter, the student should be able to

- list the types of drawings that can be found in a set of drawings and what information is contained on each of them.
- sketch 10 types of lines, identify each, and explain how they are used on mechanical drawings.
- explain the difference between mechanical and pictorial drawings.
- name all of the various views that can be shown on drawings.
- read a set of drawings and explain each item shown and its dimensioning.
- discuss why a drawing may be scaled.
- compare the differences between sketches and mechanical drawings.
- demonstrate the ability to make a sketched drawing.
- illustrate how to use graph paper to make a scaled drawing.
- list the advantages of using computer-aided drafting software to make mechanical drawings.

KEY TERMS

alphabet of lines

bill of materials

break line

cavalier drawings

centerline

cutaway

cutting plane line

detail views

dimension line

extension line

hidden line

isometric drawings

leaders and arrows

mechanical drawings

object line

orthographic projection

phantom lines

pictorial drawings

project routing information

scale

section line

section view

set of drawings

sketching

specifications

title box

vector lines

INTRODUCTION

Drawings are the tools that let us accurately communicate with each other in a very technical way. It is said that "a picture is worth a thousand words, but a mechanical drawing can be worth millions." How many words would you have to use to tell someone how to build a jet airliner, a tanker ship, or even something as simple as a door hinge? Try it. How would you describe the thickness, diameter, and angle of the countersink of the screw holes and their locations? What would be the radius of the hinge pin? And the list of things you need to describe about the making of a hinge goes on and on. We can do all of that and more with easily understood mechanical drawings.

As you look at a basic mechanical drawing, you can see the object's shape, size, and location of its parts. However, as the drawing becomes more and more complex, it can be more difficult to see how everything relates. This chapter will help you see the basic layout of mechanical drawing and how the various parts of a drawing relate.

MECHANICAL DRAWINGS

Mechanical drawings have been around for centuries. Leonardo da Vinci (1452–1519) used mechanical drawings extensively in his inventive works. Many of his drawings still exist today and are as easily understood now as when they were drawn. For that reason mechanical drawings have been called the universal language; they are produced in a similar format worldwide. Despite the few differences in how the views are laid out, **Figure 21-1**, the drawings are understandable. Notwithstanding different languages and measuring systems, the basic shape of an object and location of components can be determined from any good drawing.

A group of drawings, known as a **set of drawings**, should contain enough information to enable a welder to produce the weldment. The set of drawings may contain various pages showing different aspects of the project to aid in its fabrication. The pages may include the following: title page, pictorial, assembly drawing, detailed drawing, and exploded view, **Figure 21-2**.

In addition to the actual shape as described by the various lines, a set of drawings may contain additional information such as the title box, specifications, project routing information, and bill of materials. The **title box**, which will appear in one corner of the drawing, may contain the name of the part, company name, scale of the drawing, date of the drawing, who made the drawing, drawing number, number of drawings in this set, and tolerances.

The **specifications** detail the type and grade of material to be used, including base metal, consumables such as filler metal, and hardware such as nuts and bolts.

The **project routing information** is used in large shops where an assembly line process is used. This information lets you know where the parts are to be sent once you have completed your part of the assembly process.

A **bill of materials** can also be included in the set of drawings. This is a list of the various items that will be needed to build the weldment, **Figure 21-3**.

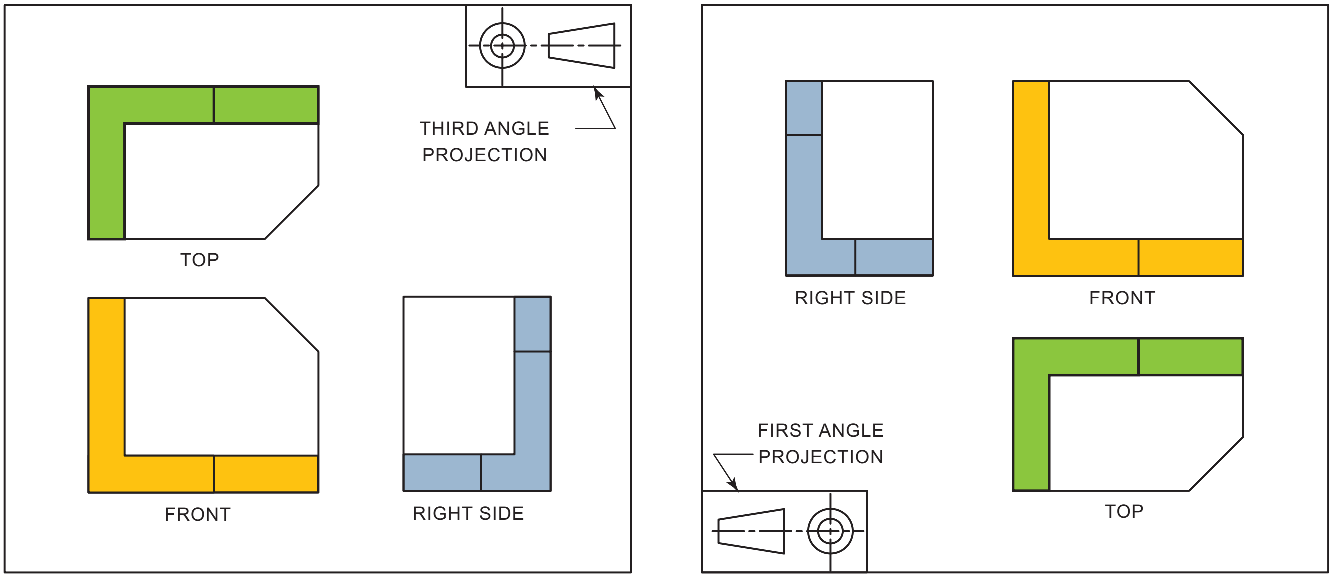


FIGURE 21-1 Of the two methods for locating the views, the third angle projection is the most commonly used for welding drawings.

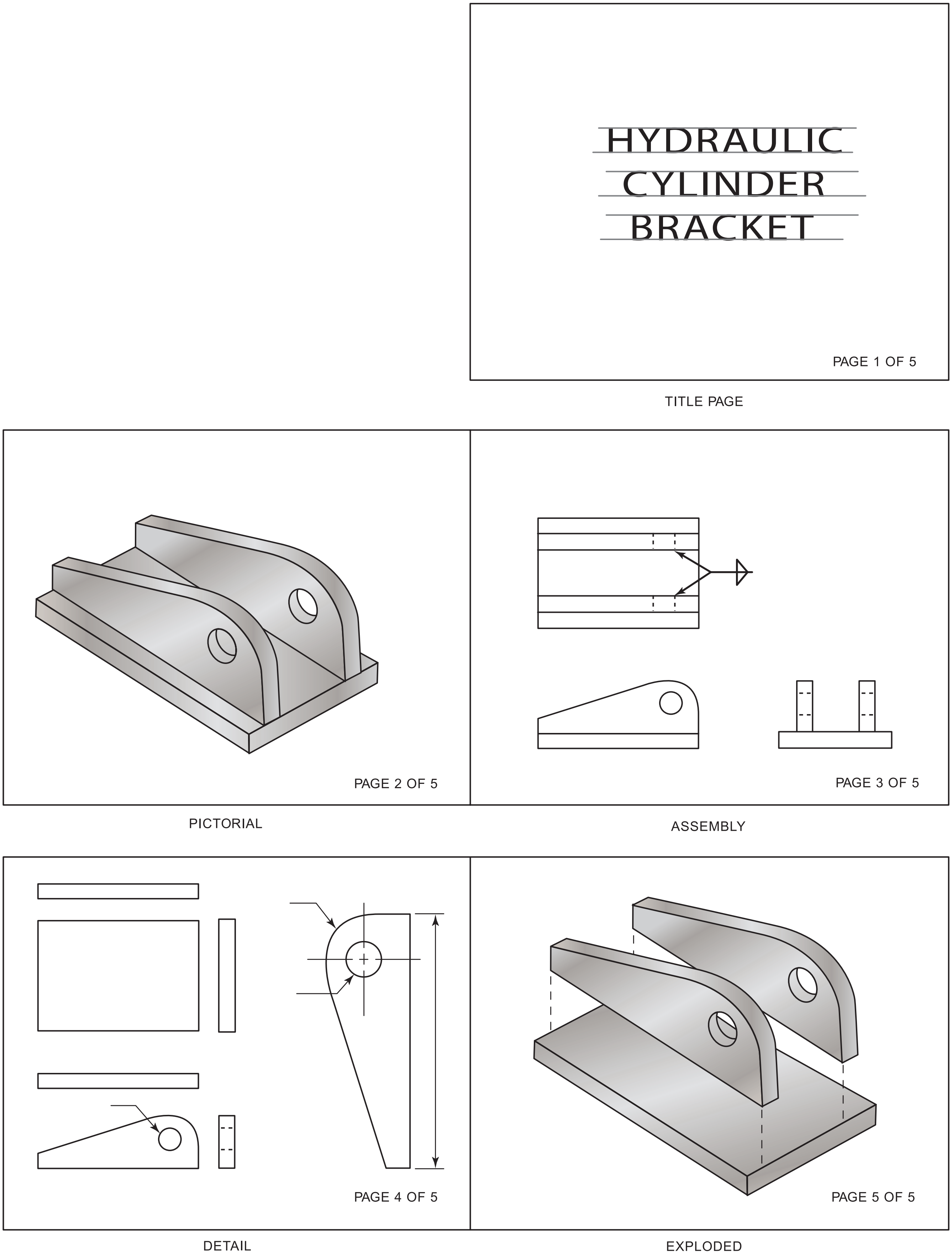


FIGURE 21-2 Examples of some of the pages that can be found as part of a set of drawings.

BILL OF MATERIALS				
Part	Number Required	Type of Material	Size	
			Standard Units	SI Units

FIGURE 21-3 Example of a bill of materials.

LINES

To understand drawings, you need to know what the different types of lines represent. The language of drawing uses lines to represent its alphabet and the various parts of the object being illustrated. Different types of lines are used to represent various parts of the object being illustrated. The various line types are collectively known as the **alphabet of lines**, **Table 21-1** and **Figure 21-4**.

(A) **Object lines**—Object lines show the edge of an object, the intersection of surfaces that form corners or edges, and the extent of a curved surface, such as the sides of a cylinder.

(B) **Hidden lines**—Hidden lines show the same features as object lines except that the corners, edges, and curved surfaces cannot be seen because they are hidden or obscured behind the surface of the object.

(C) **Centerlines**—Centerlines show the center point of circles, arcs, round, or symmetrical objects. They also locate the center point for holes, irregular curves, and bolts.

(D) **Dimension lines**—Dimension lines are drawn so that their ends touch the object being measured, or they may touch the extension line extending from the object being measured. Numbers in the dimension line or next to it give the size or length of an object.

(E) **Extension lines**—Extension lines are the lines extending from an object that locate the points being dimensioned.

(F) **Cutting plane lines**—Cutting plane lines represent an imaginary cut through the object. They are used to expose the details of internal parts that would not be shown clearly with hidden lines.

(G) **Section lines**—Section lines show the surface that has been imaginarily cut away with a cutting plane line to show internal details. Different types of materials, such as steel and cast iron, can be identified by using different patterns of section lines. Although there are different patterns for different materials, most often the evenly spaced diagonal lines for cast iron are used for all cut surfaces.

(H) **Break lines**—There are two types of break lines—long break lines and short break lines. Both show that part of an object has been removed. This is often done when a long uniform object needs to be shortened to fit the drawing page.

(I) **Leaders and arrows**—Leaders (the straight part) and arrows (the pointed end) point to a part to identify it, show the location, and/or are the basis of a welding symbol.

(J) **Phantom lines**—Phantom lines show an alternate position of a moving part or the extent of motion such as the on/off position of a light switch. They can also be used as a place holder for a part that will be added later.

Types of Drawings

Drawings used for most welding projects can be divided into two categories—pictorial and mechanical drawings.

Pictorial Drawings

Pictorial drawings present the object in a realistic and more easily understandable form. These drawings usually appear as one of two types, isometric or cavalier, **Figure 21-5**. The more realistic perspective drawing form is seldom used for welding projects.

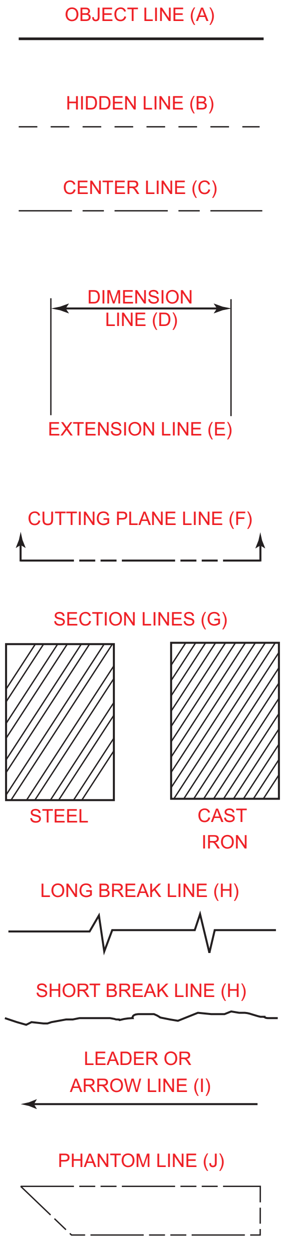


TABLE 21-1 Alphabet of Lines

Isometric Drawing Of the two types of pictorial drawings, the **isometric drawings** are more picture-like. Isometric drawings are drawn at a 30° angle so it appears that you are looking at one corner. As with all drawings, all the lines that are parallel on the object appear parallel on the drawing.

Cavalier Drawings On **cavalier drawings**, one surface, usually the front, is drawn flat to the page. It appears just like the front view of a mechanical drawing. The lines for the top and side surfaces are drawn back at an angle, usually 30°, 45°, or 60°.

Mechanical Drawings

Mechanical drawings are made as if you were looking through the sides of a glass box at the object and tracing its shape on the glass, **Figure 21-6A**. If all of the sides of the object were traced and the box unfolded and laid out flat, **Figure 21-6B**, then there would be six basic views shown, **Figure 21-6C**. This type of drawing is also called an **orthographic projection**.

Usually, not all of the six views of a weldment are required to build it. Only those needed are normally provided, usually only the front, right side, and top views. Sometimes only one or two of these views are needed.

The front view is not necessarily the front of the object. The front view is selected because when the object is viewed from this direction, its overall shape is best described. As an example, the front view of a car or truck would probably be the side of the vehicle because viewing the vehicle from its front may not show enough detail to let you know whether it is a car, light truck, SUV, or van. From the front most vehicles may look very similar.

Special Views

Special views may be included on a drawing to help describe the object so it can be made accurately. Special views on some drawings may include the following:

- *Section view:* The **section view** is drawn as if part of the object were sawn away to reveal internal details, **Figure 21-7**. This view is useful when the internal details would not be as clear if they were shown as hidden lines. Sections can be either fully across the object or just partially across it. The imaginary cut surface is set off from other noncut surfaces by section lines drawn at an angle on the cut surfaces. Some drawings use specific types of section lines to illustrate the type of material that the part was made with. The location of this imaginary cut is shown using a cutting plane line, **Figure 21-8**.
- *Cutaways:* The **cutaway** view is used to show detail within a part that would be obscured by the part's surface. Often a freehand break line is used to outline the area that has been imaginarily removed to reveal the inner workings.
- *Detail views:* The **detail view** is usually an external view of a specific area of a part. Detail views show small details of a part's area and negate the need to draw an enlargement of the entire part. If only a small portion of a view has significance, then this area can be shown in a detail view, either at the same scale or larger if needed. By showing only what is needed within the detail, the part drawn can be clearer and does not require such a large page.
- *Rotated views:* A rotated view can be used to show a surface of the part that would not normally be drawn square to any of the six normal view planes. If a surface is not square to the viewing angle, then lines may be distorted. For example, when viewed at an angle, a circle looks like an ellipse, **Figure 21-9**.

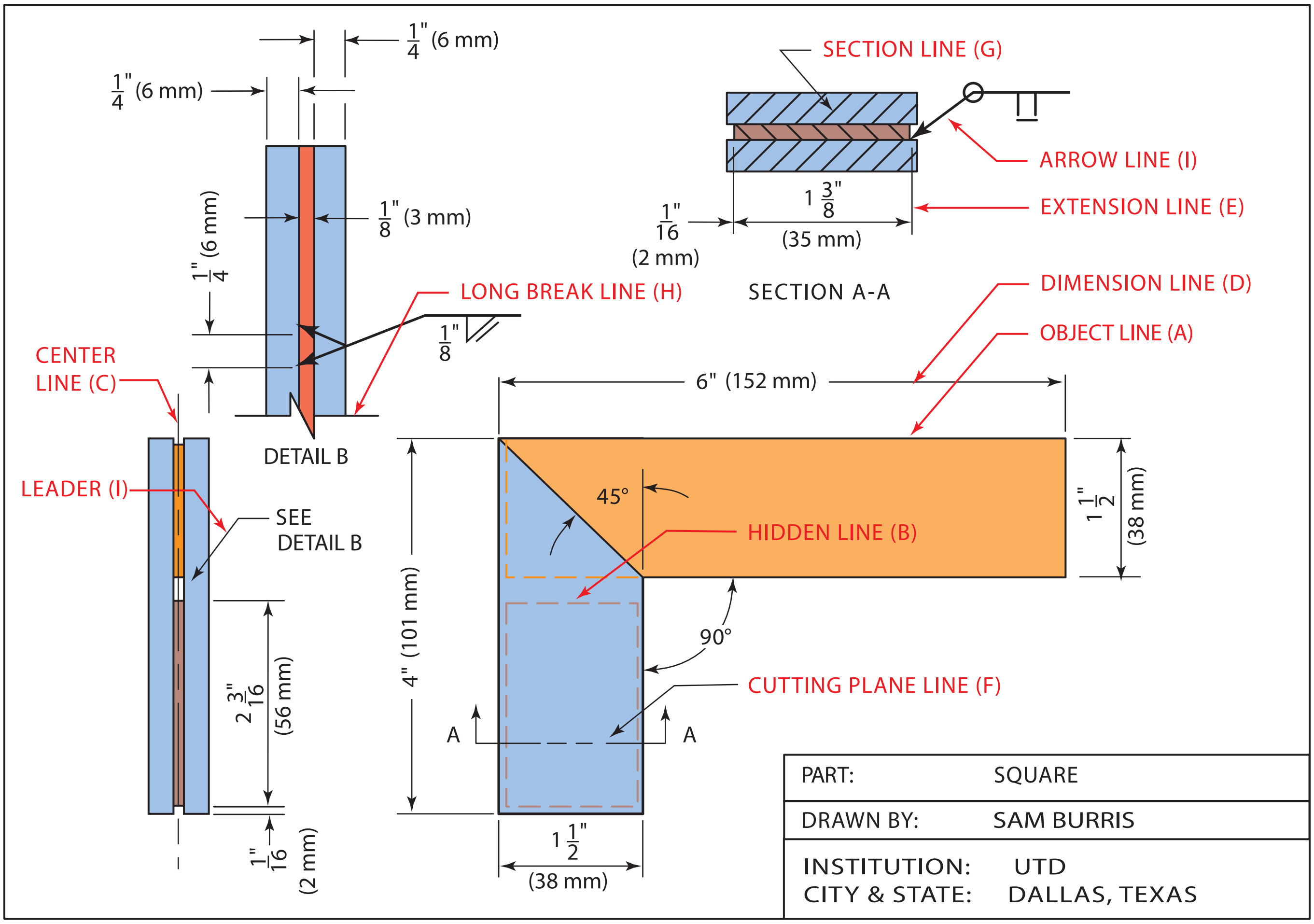


FIGURE 21-4 Drawing showing alphabet of lines.

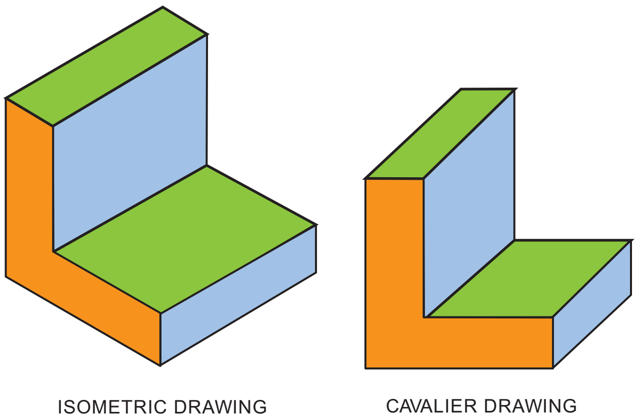


FIGURE 21-5 Two common ways of showing a pictorial drawing.

DIMENSIONING

The drawing should have all of the dimensions necessary to fabricate the weldment. Sometimes it may be necessary to look at other views to locate all of the dimensions required to build the object. By knowing how the views are arranged, it becomes easier to locate dimensions. Length dimensions can be found on the front and top views. Height dimensions can be found on the front and right-side views. Width dimensions can be found on the top and right-side views, **Figure 21-10**. The locating of dimensions on these views is consistent with both the first angle perspective or third angle perspective layouts.

If the needed dimensions cannot be found on the drawings, do not try to obtain them by measuring the drawing itself. Even if the original drawing was made very accurately, the paper it is on changes size with changes in humidity. Copies of the original drawing are never the exact same size. The most acceptable way of determining missing dimensions is to contact the person who made the drawing.

Keep the drawing clean and well away from any welding. Avoid writing or doing calculations on the drawing unless you are noting changes. Often there is a need to make a change in the part as it is being fabricated. When these changes are added to the "as drawn" drawing, the drawing is referred to as the "as built" drawing. It is important to keep these "as built" drawings so that they will be filed following the project for use at a later date. The better care you take with the drawings, the easier it will be for someone else to use them.

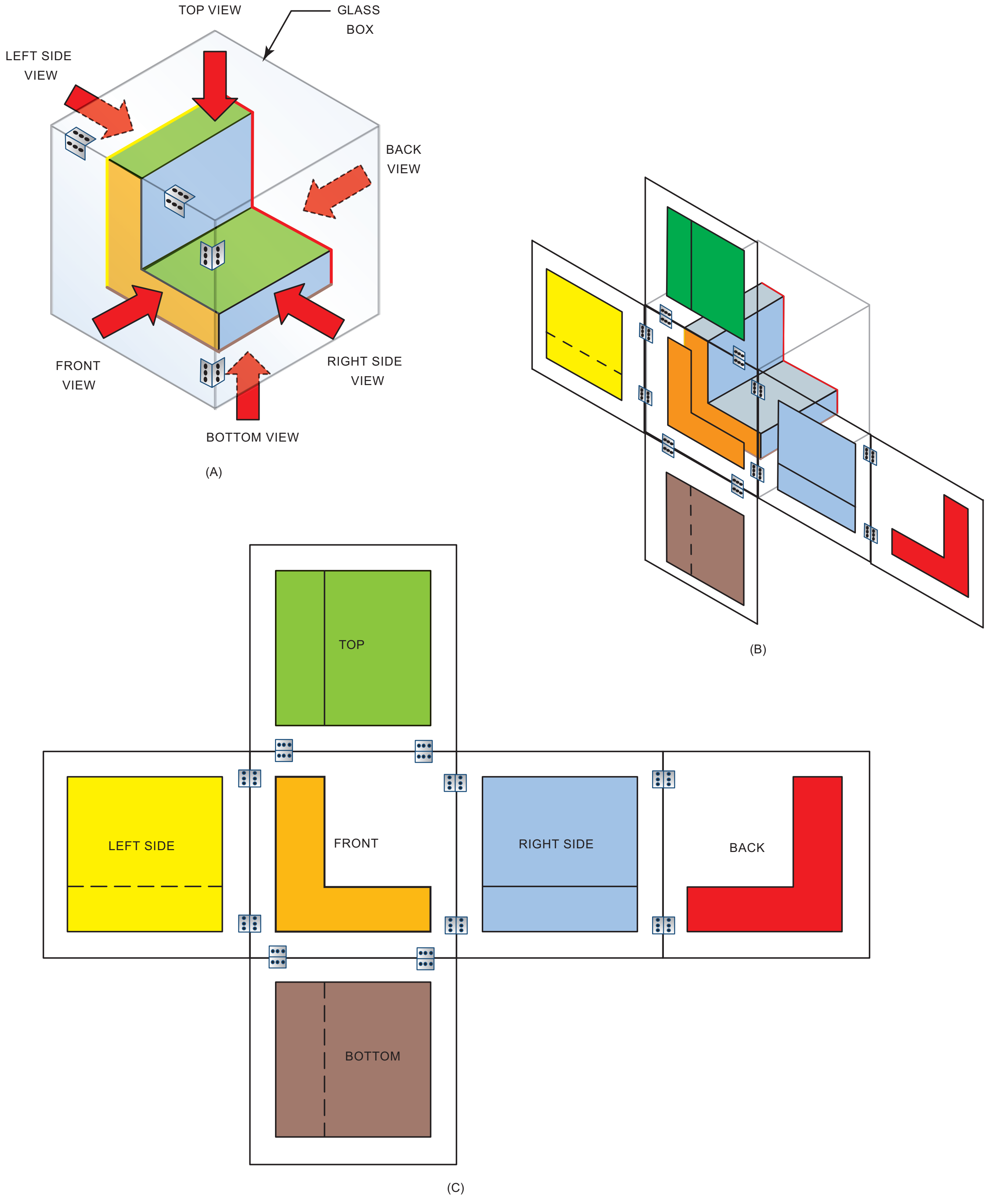


FIGURE 21-6 (A) Viewing an object as if it were inside a hinged glass box. (B) This is what you would see if you traced the views seen through the glass box and unfolded it. (C) Arrangement of the six views of the sides of the box as shown by the third angle projection method.

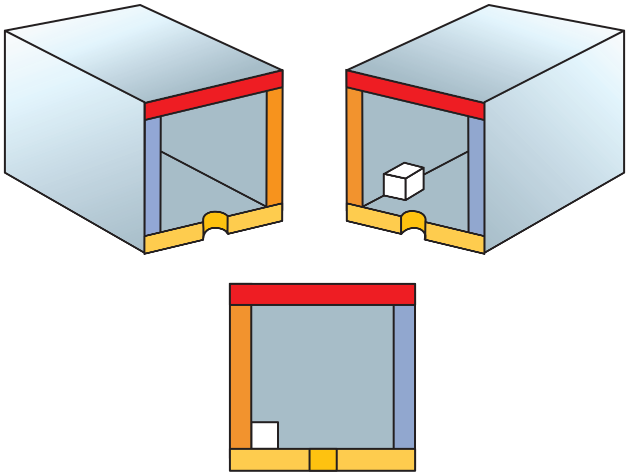


FIGURE 21-7 Section drawing.

DRAWING SCALE

It would not be possible to make every drawing the same size as the parts being made, and for that reason you must change the scale or size of the drawing. When we use a **scale**, we are saying that the part being drawn is drawn smaller or larger than it really is. An easy scale to use is 1 in. equals 1 ft, so that if we draw a line that is 10 in. long, it represents an actual distance of 10 ft. To aid in making and reading scaled drawings, you can use a drafting tool called a *scale*, **Figure 21-11**. A scale is a special type of ruler that is marked with different units. There are two commonly used scales, the architectural scale and the engineering scale. The architectural scale is the one that is most often used for mechanical welding drawings.

Architectural scales are divided into fractions of inches. Some of the common units are 1/8, 3/32, 1/4, 3/16, 3/8, and 3/4. These scales can be used to represent different lengths and units of measure. For example, the 1/4 scale can be used with inches so that 1/4 in. equals 1 in. or to

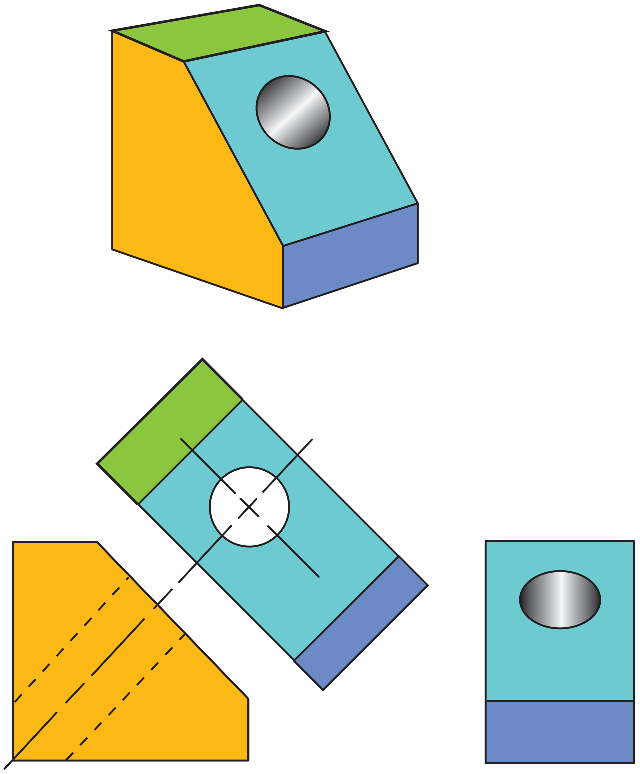


FIGURE 21-9 Notice that the round drilled hole looks misshapen or elliptical in the right-side view.

represent feet as in 1/4 in. equals 1 ft. It could be used with yards, meters, miles, or any other standard unit.

Engineering scales are divided into decimals of inches. Some of the common units are 10th, 20th, 30th, 40th, 50th, and 60th. As with the architectural scale, these units can be used to represent any number of distances.

Not all drawings are scaled down; some are made larger, **Figure 21-12A**. Most often, details are drawn at a larger scale so that the important parts can be seen more clearly, **Figure 21-12B**.

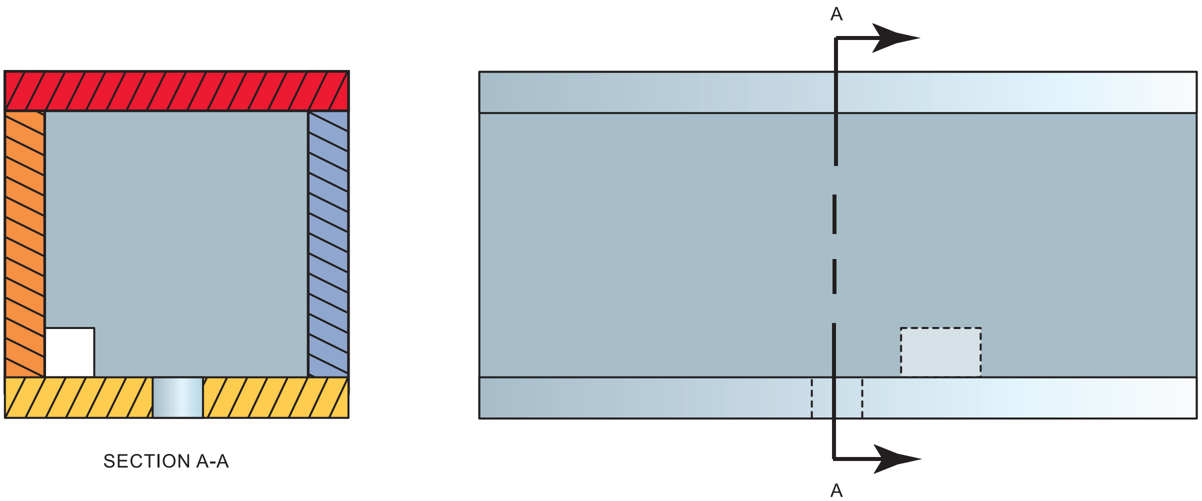


FIGURE 21-8 Cutting plane line and section.

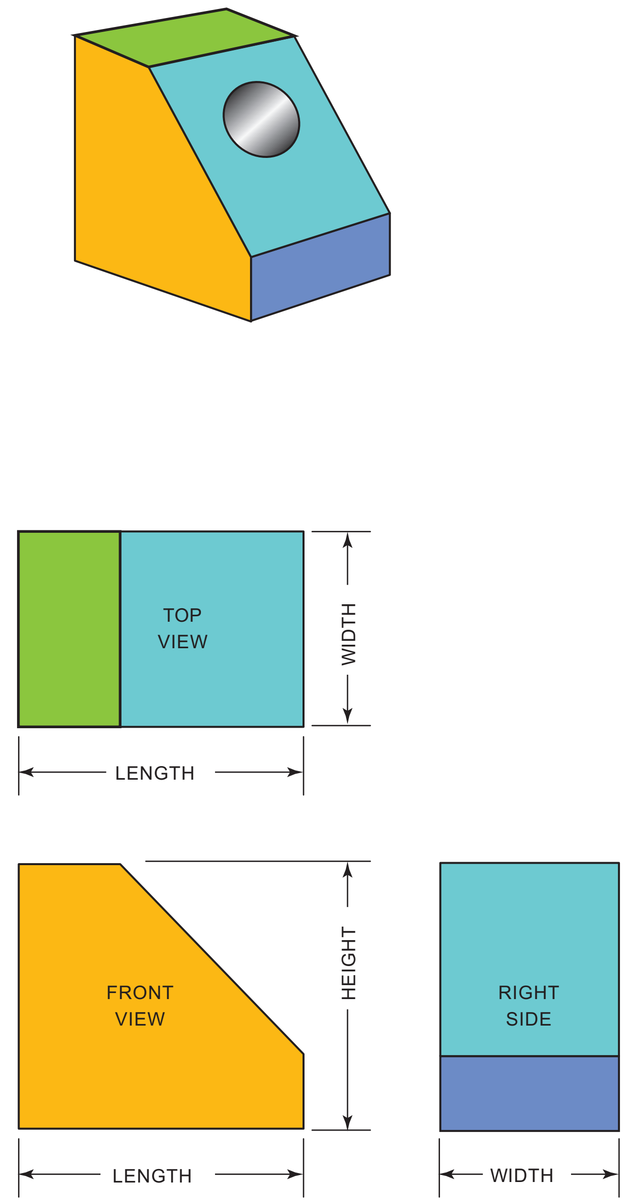


FIGURE 21-10 Locations where length, width, and height dimensions can be found on the three views of a drawing.

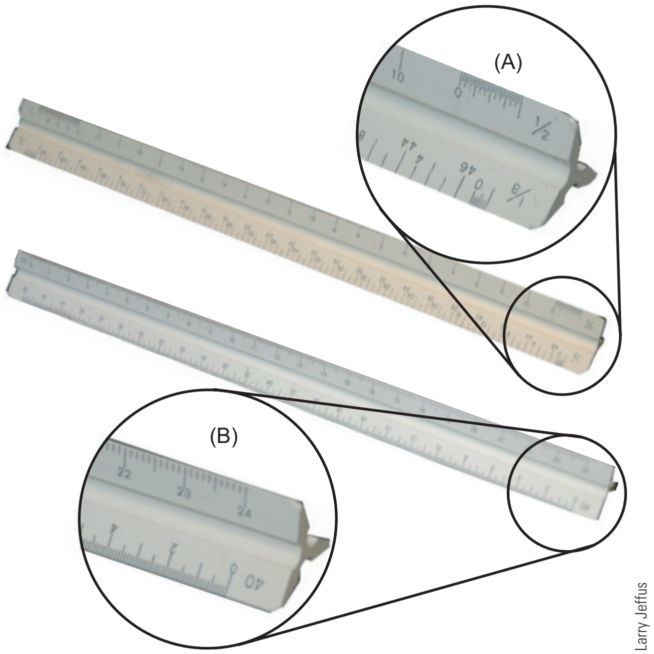


FIGURE 21-11 (A) Architectural scales may have 12 different measuring units on a single triangular-shaped scale. (B) Engineering scales usually have only six different measuring units on their scales.

READING MECHANICAL DRAWINGS

The pictorial drawing of the block in the glass cube shown in Figure 21-6A is color-coded. The same color-coding has been used for all of the multiview drawings in this chapter to help you identify the views. **Table 21-2** lists the colors and views used. The front surface in all the views is colored orange, the top view is green, the right side is blue, the left side is yellow, and the bottom is brown. Mechanical drawings you work with in the field are not color-coded.

In addition, the lines that represent the hidden surfaces of the block in the glass cube have been color-coded. For example, you can see the red line for the back visible on the top and right-side views.

The color-coding is intended to help you learn how to read a mechanical drawing. The important element to remember is that the front view is the main view. The standard views include the front, top, and right-side views. Not all drawings use all of the standard views and may or may not include additional views. For that reason, you need to know where each of the views are and how they relate to each other.

PRACTICE 21-1

Reading Mechanical Drawings

Using a pencil and lined paper, you are going to identify the color of the surfaces shown in the three-view drawing as shown on the pictorial view, **Figure 21-13**, and the color of the surface identified in the pictorial drawing as they are shown in the three-view drawing in **Figure 21-14**. Use Table 21-2 to identify the colors of the surfaces.

Write the numbers 1 through 6 vertically down the left side of the paper. Looking at Figure 21-13, write the name of the color for the surface shown.

Write the letters A through L down the left side of the paper. Looking at Figure 21-14, write the name of the color for the surface as it appears in the three-view drawing. ◆

Sketching

Sketching is a quick and easy way of producing a drawing that can be used in the welding shop. Sketches and mechanical drawings have some similarities and some

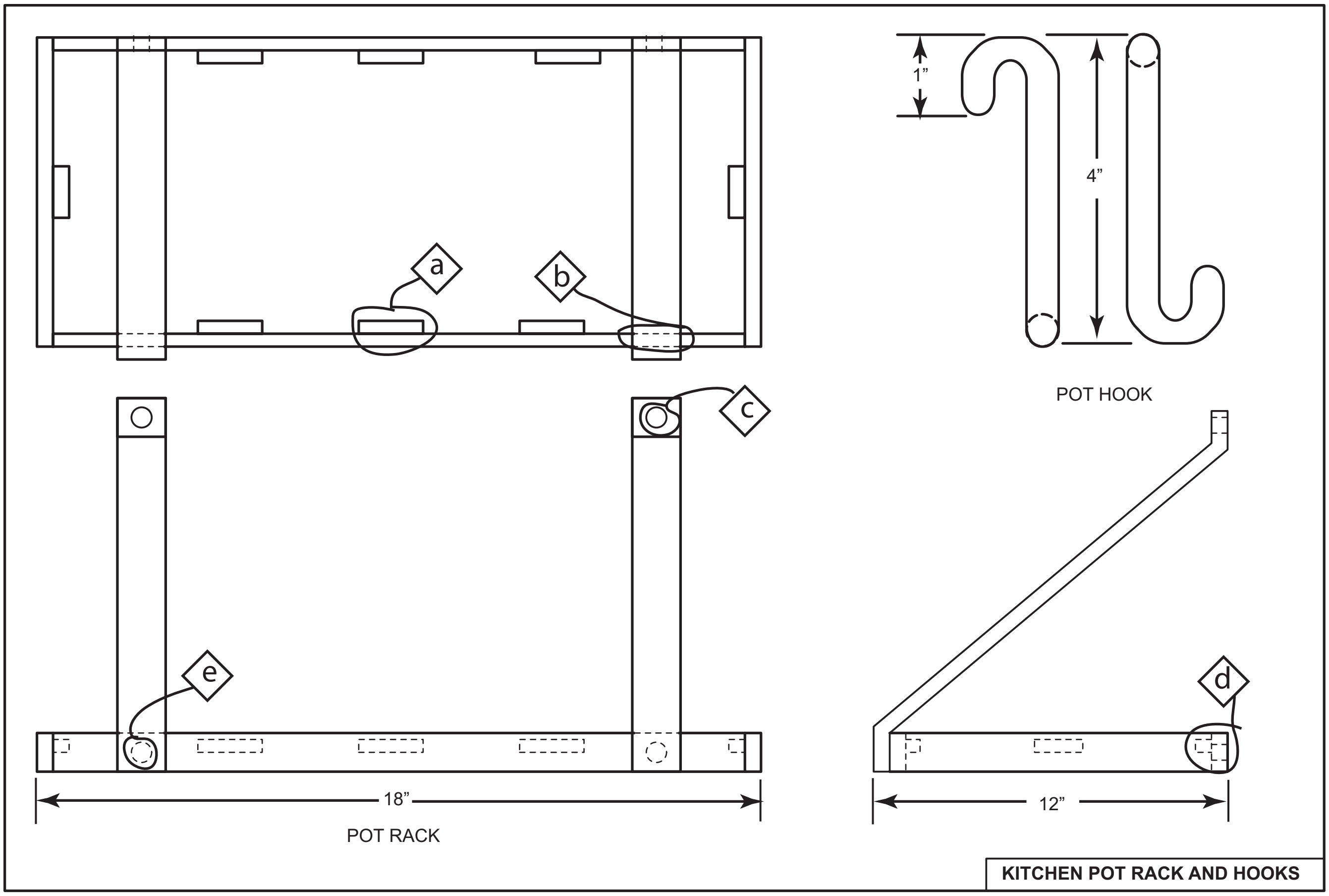


FIGURE 21-12 (A) The pot rack was scaled down to fit the drawing page, and (B) the detail of the pot hook was scaled up to show more detail.

MECHANCIAL DRAWING VIEW COLOR CODES			
VIEW NAME	VIEW COLOR	VIEW NAME	VIEW COLOR
FRONT	ORANGE	LEFT SIDE	YELLOW
TOP	GREEN	BACK	RED
RIGHT SIDE	BLUE	BOTTOM	BROWN

TABLE 21-2 View Color Code

differences. They are similar in that they both contain the necessary information to produce a welded project. The main way they are different is that a sketch is a quick way of drawing an object and sketches may not be drawn to scale. Mechanical drawings take more time and are drawn to scale. They both should contain all the necessary information to build the desired weldment.

NOTE

When graph paper is used, sketches can be easily drawn to scale, **Figure 21-15**.

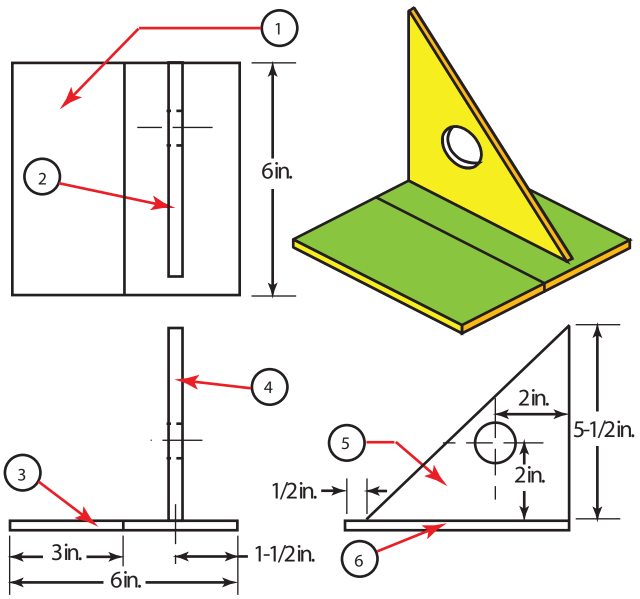


FIGURE 21-13 Practice 21-1: Reading mechanical drawings.

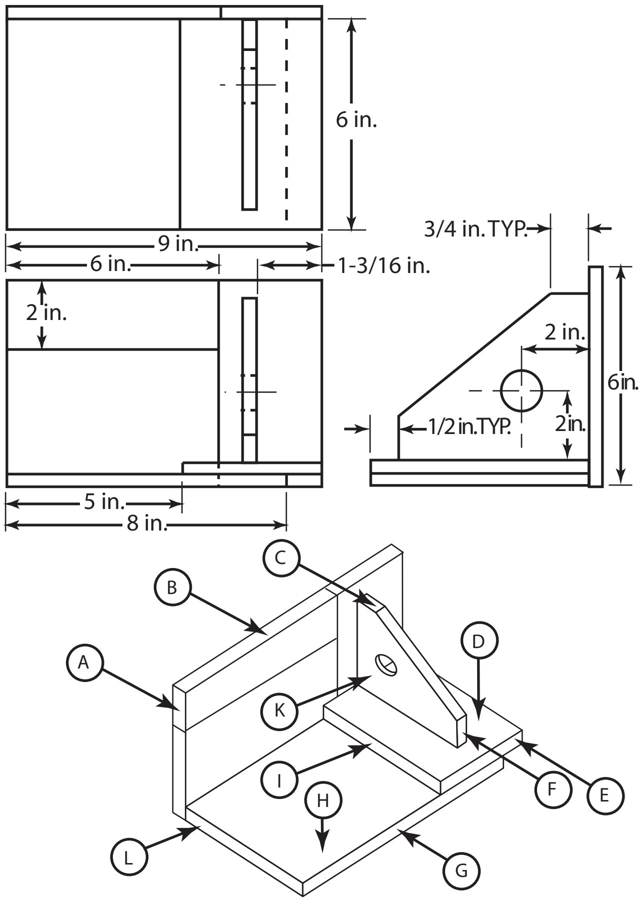


FIGURE 21-14 Drawing surface identification.

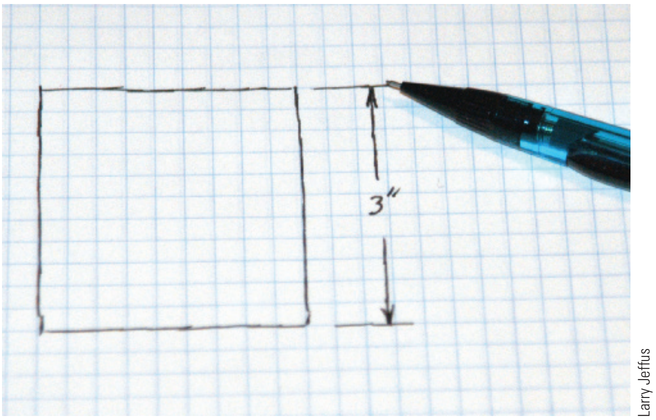


FIGURE 21-15 Graph paper makes it easier to sketch to scale.

A sketch can be any drawing that is made without the extensive use of drafting instruments or computer-aided design (CAD). Sketches are generally drawings that are made in the shop by the welder, shop supervisor, or by the customer. A sketched drawing can be made with or without the use of drawing tools such as scales, straightedges, curves, and circle templates, **Figure 21-16**. When drawing tools are used, the drawing may have straighter lines but take longer to produce. Straight lines are not

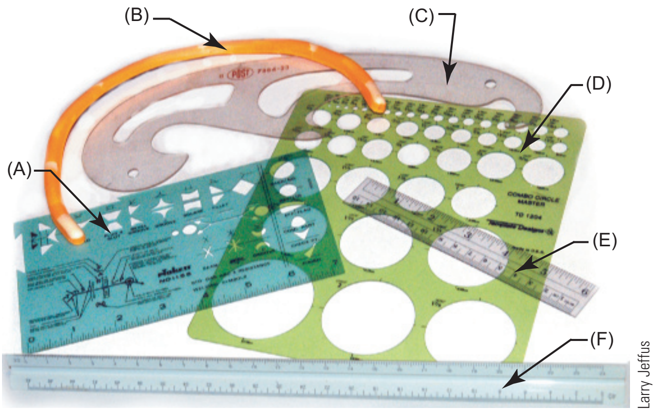


FIGURE 21-16 A number of tools can aid in drawing. These are a few different types: (A) welding symbol template; (B) flexible curve; (C) French curves; (D) circle template; (E) straightedge/rule; and (F) drafting scale.

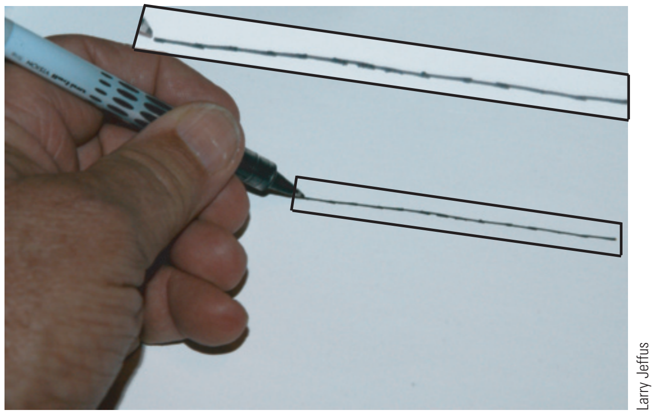


FIGURE 21-17 When sketching a line, rest your hand on the paper and make quick, short strokes as shown in the insert.

always necessary to the actual production of the parts being welded as long as the drawing is clear.

Sketching is the process of making a line on a drawing by making a series of quick, short strokes with the pencil or pen, **Figure 21-17**. The technique of sketching a line may seem slow and awkward at first as compared to just holding the pencil on the paper and drawing a line. But a sketched line can be much straighter and faster once you have developed the skill. Each stroke may not be straight, but the line produced can be straight.

PRACTICE 21-2

Sketching Straight Lines

Using a pencil and unlined paper, you are going to sketch a series of 6-in.-long straight lines.

Practice sketching from the right to the left and left to the right. You may find that it is easier for you to go one direction than the other. The direction you sketch is not as important as your ability to make straight lines.

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FIGURE 21-18 It is fine if the width of a sketched line varies slightly as a result of your making slight changes as you draw the line.

Start by making a small mark or dot approximately 6 in. from the point you plan on starting your sketched line. Don't measure; just estimate the distance. Part of being able to make quick sketches is the ability to judge lengths. The mark will give you an aiming point. Look at the point as you start the series of short sketched marks. Make each sketch mark approximately 1/2 in. to 3/4 in. long and make them in a quick, smooth series. Overlap each mark so they form a solid line, **Figure 21-18**. You may want to make the sketched line very light initially and go back over it to make it darker. It may be easier to make the sketch marks in the direction of travel or in the opposite direction—try both.

Once you have completed six or eight lines, lay a straightedge next to the lines and see how straight you were able to make them. Keep practicing sketching straight lines until you are able to make 6-in.-long lines that are within ± 1/8 in. of being straight, **Figure 21-19**. ◆

PRACTICE 21-3

Sketching Circles and Arcs

Using a pencil and unlined paper, you are going to sketch a series of circles.

Start by sketching two light construction lines that cross at right angles. Construction lines are often used in drawings as guides to the finished line. Construction lines should be very light so they can be left on the drawing or easily erased.

Make two marks on each of the construction lines approximately 1/2 in. from the center point. These points will serve as your aiming points as you sketch the circle. The circle you sketch will be tangent to these points. A tangent straight line is one that meets a circle at a point where the circular line and straight line are going in the same direction. When a 12-in. ruler is placed on a round pipe, where the ruler and pipe meet is the tangent point. If you were to make a short straight line at the tangent point and keep doing this all the way around the pipe, then you would wind up with a circle drawn from a series of short straight lines, **Figure 21-20**.

Sketching a tangent line starting at the top mark, keep sketching and gradually turn the line toward the mark on the next construction line. Once you have completed the first quarter of the circle, you may find it easier to continue if you turn the paper. Repeat the sketching process until you have completed sketching the circle.

Repeat this process making circles of several different sizes. On larger circles it may be helpful to make more construction lines. Using a circle template, check your circles for accuracy. Continue making sketched circles until you can draw them in several sizes within ± 1/8 in. of round. ◆

NOTE

Sometimes it is easier to draw small circles in a square box. You can do this by first drawing a box using construction lines and then drawing the circle inside the box.

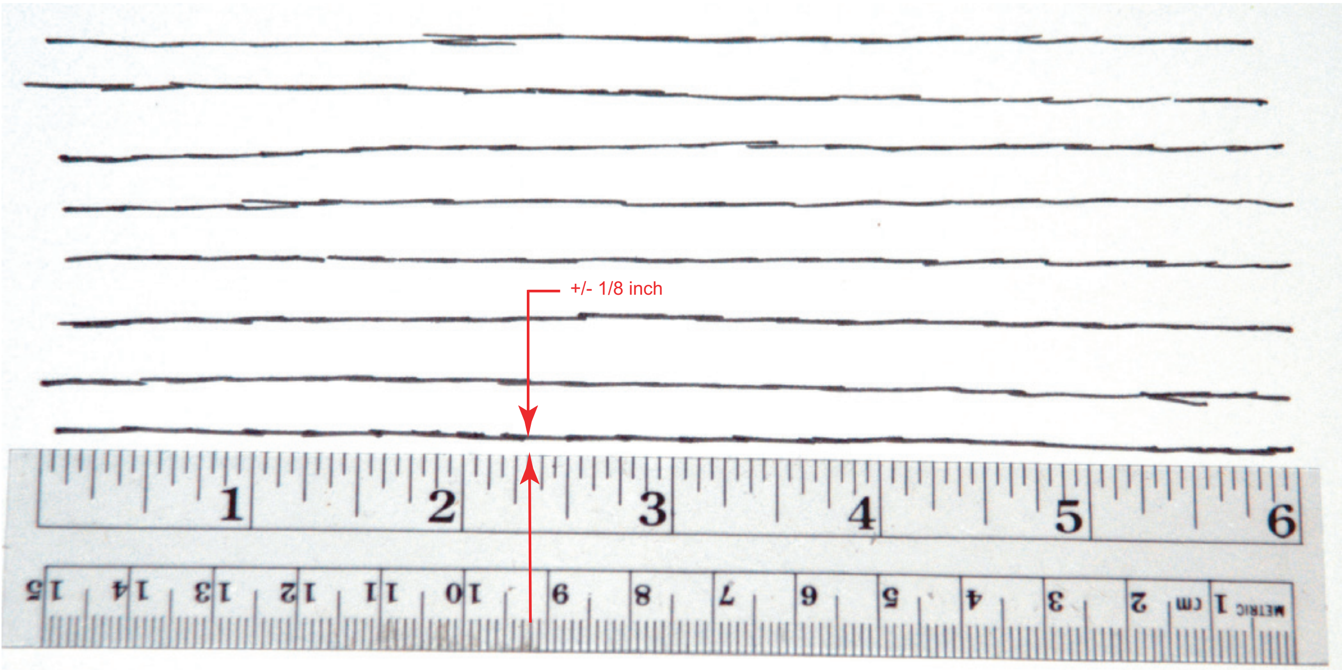

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FIGURE 21-19 Practice 21-2: Sketch 6-in.-long straight lines.

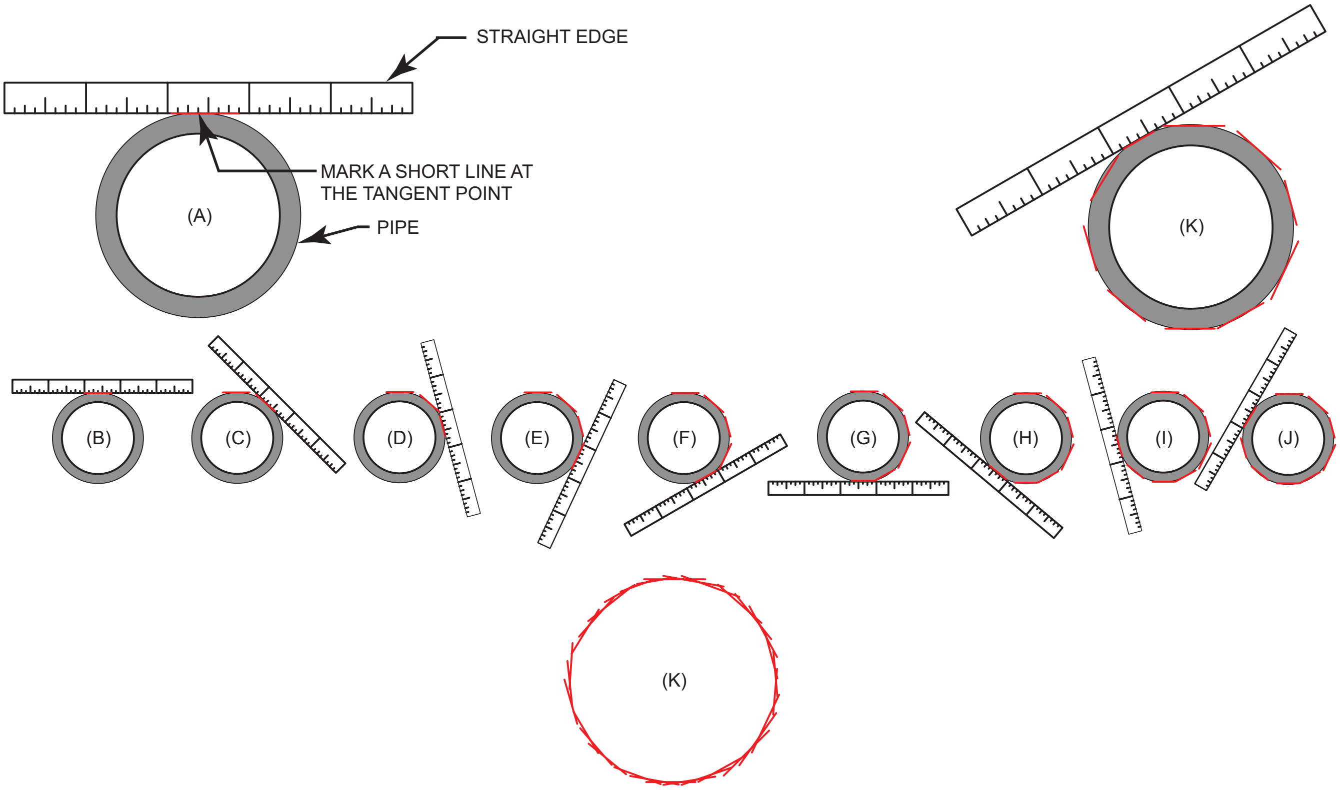

FIGURE 21-20 As you can see, a smooth circle can be sketched with short straight lines.

PRACTICE 21-4

Sketching a Block

Using a pencil and unlined paper, you are going to sketch a mechanical drawing showing three views of a block as shown in **Figure 21-21**.

NOTE

In the mechanical drawing type called *orthographic projection*, the views must be arranged properly. The top view is drawn straight above the front view, and the right-side view is aligned to the right. This arrangement makes it possible for you to see distinguishing lines in one view and locate the corresponding lines in another view. This is how you find all of the location dimensions or even how you can identify material. For example, in one view an angle iron might be shown as parallel lines, whereas in another view you would see the distinctive "L" shape. The same would apply to a cylinder that would appear as parallel lines in one view but as a circle in a different view.

Start by sketching construction lines as shown in **Figure 21-22A**. These lines will form the boxes for the front, top, and right-side views. Darken the lines that make up the object's lines so it is easier to see, **Figure 21-22B**.

Repeat this practice using the shaped objects shown in **Figure 21-23**. ◆

PRACTICE 21-5

Sketch a Candlestick Holder

Using a pencil and unlined paper, you are going to sketch a three-view mechanical drawing of the candlestick holder shown in **Figure 21-24**.

To lay out the angle for the candlestick holder, draw a vertical centerline that is 8 in. long. Draw the 2-in.-long top line centered on the centerline. Measure down the correct distance from the top and draw the 4-in.-long bottom line centered on the centerline. Connecting the endpoints of the top and bottom lines will automatically give the angle. But, most importantly, remember that sketches do not have to be exactly to scale as long as all of the needed dimensions are shown.

Repeat the process using the candlestick holder shown in **Figure 21-25**. ◆

ERASERS AND ERASING

Most pencil erasers have an abrasive action on the paper as they are used to erase pencil marks. This can sometimes cause the top surface of the paper to be roughed up or rubbed off. If you are not careful in erasing with a pencil

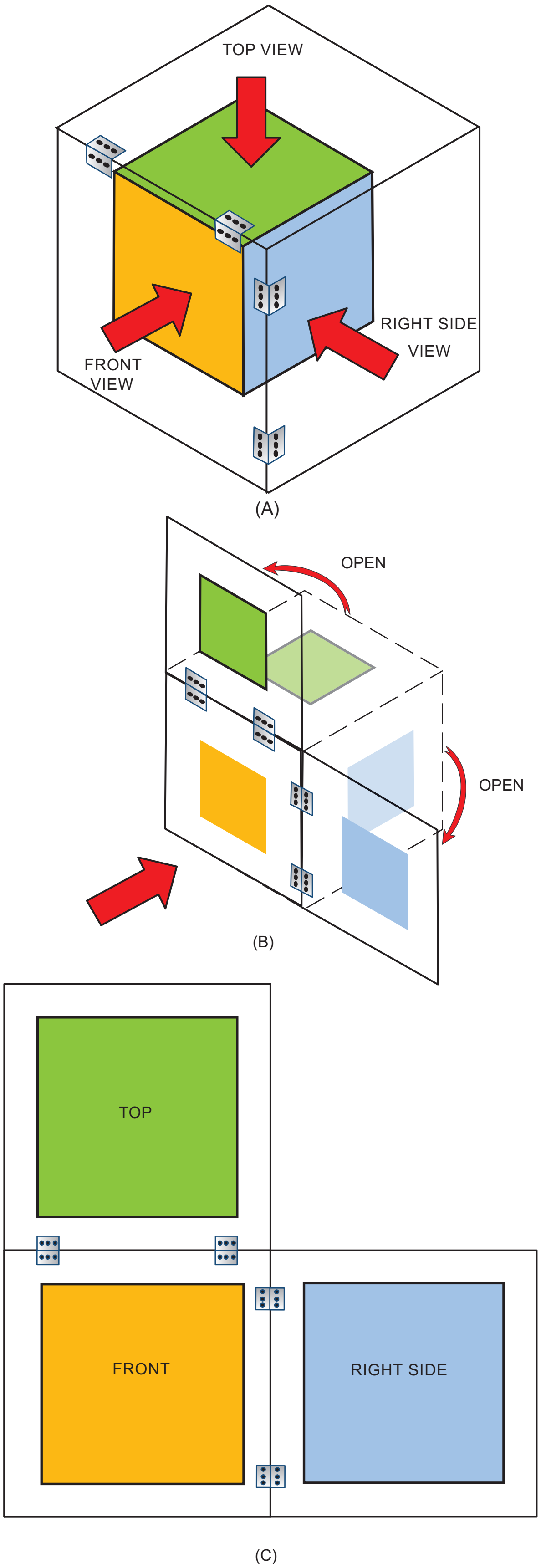

FIGURE 21-21 Practice 21-4: Sketch three views of the block; remember to keep the views in alignment as if they were traced on the sides of a hinged glass block.

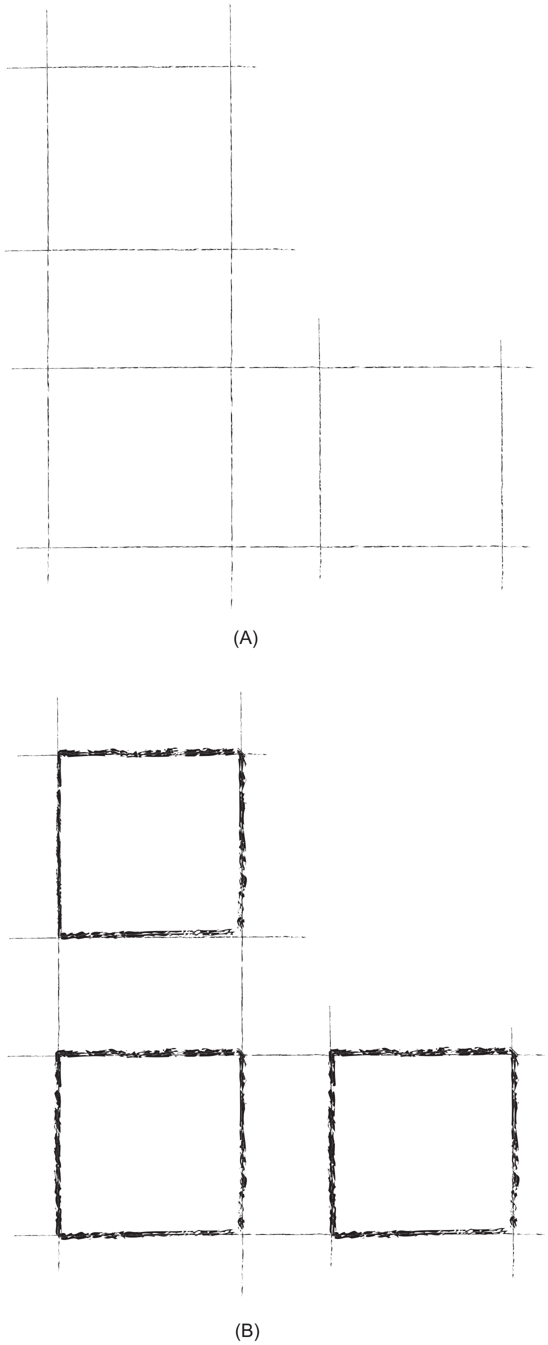

FIGURE 21-22 (A) Use lightly sketched construction lines to lay out the views. (B) If the construction lines are light enough, they may be left once the block is sketched darker.

eraser, you can damage the paper's surface, making it hard to redraw over that area.

Plastic erasers are usually white, and these erasers do not have an abrasive and will not damage the paper's surface like pencil erasers. Plastic erasers are very effective in removing unwanted pencil lines.

Sometimes you need to erase a small part of a line without removing or smudging a nearby line. There are thin metal tools called "eraser shields" that are used in drafting

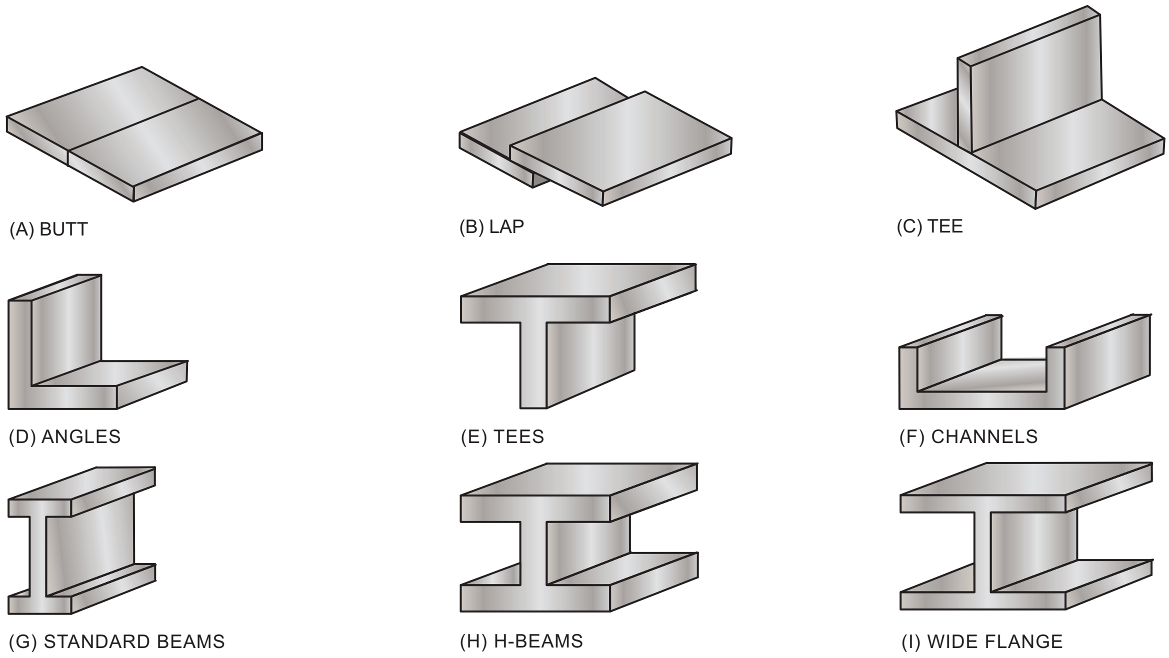

FIGURE 21-23 Practice 21-4: Additional blocks to be sketched.

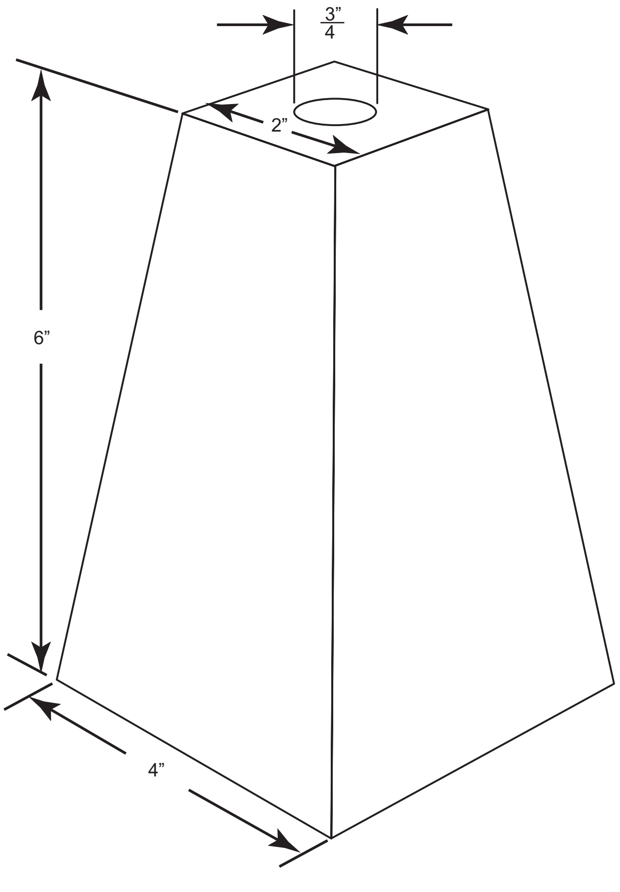

FIGURE 21-24 Practice 21-5: Sketch three views of this candlestick holder.

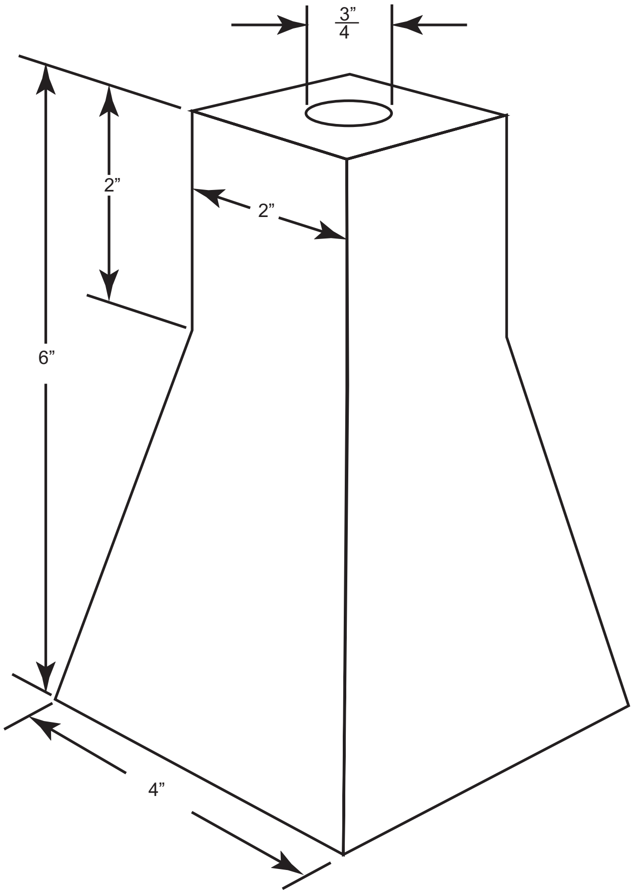

FIGURE 21-25 Practice 21-5: Additional candlestick holder to sketch.

FIGURE 21-26 Thin metal eraser shield.

to protect the neighboring line from erasure, **Figure 21-26**. An easy substitute for this tool is any scrap piece of paper. Simply cover the line you do not want to erase and rub the eraser away from the edge so the edge is not wrinkled, and then uncover the line being protected.

NOTE

A Post-it® Note makes a great temporary eraser shield.

Both correction tape and correction fluid do not erase errors, but they cover them so corrections can be made. They are easy to use and work well; however, if you are drawing with a pencil, then they may be more difficult to draw over than an erased line.

GRAPH PAPER

Making a sketch on graph paper is a way of both making your drawing more accurate and speeding up the sketching process. Graph paper is available with grid sizes ranging from 1/8-in. to 1/4-in. squares, **Figure 21-27**. Other sizes are available. Many copiers do not copy the light blue or light green lines on graph paper; therefore, if you need the lines later, you may need to make the copy machine copy darker or use another color of lined paper. Usually, the inch lines are a little darker on the graph paper, which makes it easier to count when measuring.

Even though you have lines to follow on graph paper, you may find that you can make a better-looking drawing by sketching over the grid lines rather than trying to just follow the grid line with your pencil. Graph paper does lend itself to the use of straightedges and other drafting tools; however, with practice, sketching is faster and works well.

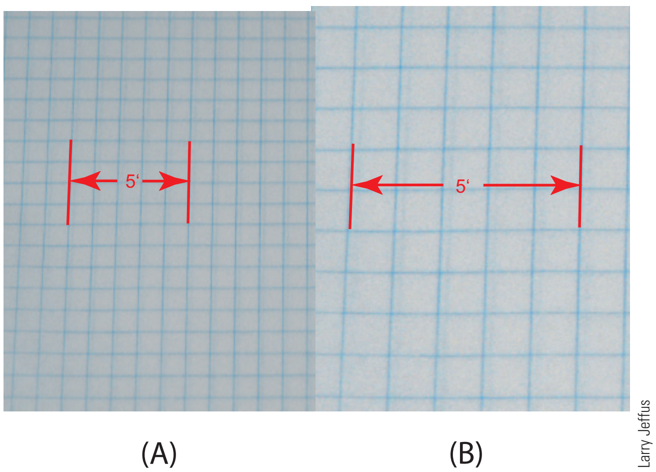

FIGURE 21-27 A sketched 5-ft-long line would be much shorter on the (A) 1/8-in. graph paper than it is on the (B) 1/4-in. graph paper.

PRACTICE 21-6

Sketching the Parts of a Workmanship Qualification Test

Using a pencil and graph paper, you are going to sketch the front views of the parts needed to fabricate this SENSE Workmanship Qualification Test weldment labeled A through F in **Figure 21-28**.

The first thing you need to do is find the largest piece and determine what would be the best scale to use on the graph paper you are using. If you select too large of a scale, then the parts will not fit on the paper; if you pick too small of a scale, then it will be hard to dimension.

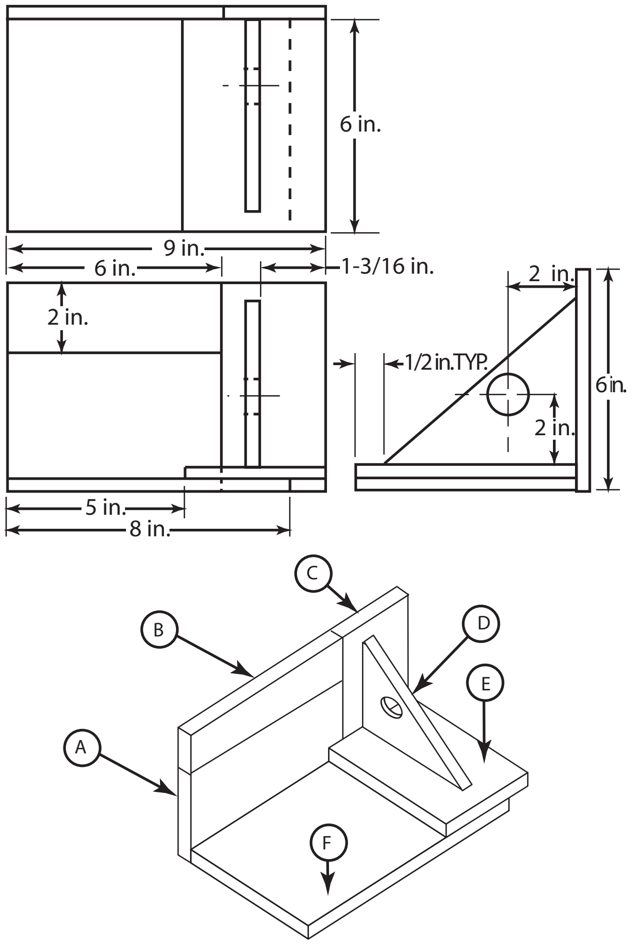

FIGURE 21-28 Practice 21-6: Sketching the parts of a Workmanship Qualification Test.

The material is 10 ga to 14 ga, so if it were to be drawn it would just be two parallel lines that are very close to each other. For that reason, only the front views are required.

Locate the two dimensions that relate to part A. Count off the number of squares on the graph paper for the length and make a mark. Count off the number of squares and mark the width. Sketch lines between the four corners of part A. Sketch extension lines and dimension lines and write the length and width dimensions. Repeat this process until required parts of all six pieces have been sketched and labeled. ◆

PRACTICE 21-7

Sketching Curves and Irregular Shapes

Using a pencil and graph paper, you are going to sketch a front view of the plant hanger shown in **Figure 21-29**.

Curves and irregular shapes can be easily drawn using a grid such as that found on graph paper. The first thing you need to do is locate a series of points on the graph paper that coincide with points on the curve you are copying. Start with the easy points where the lines on the paper cross at a point on the object. For example, one end of the curve starts at the intersection of lines E-3, so put a dot there. Next, the curve is tangent to lines F-2, so put a dot there. Follow the curve around, putting additional dots at the other intersecting points.

Once all of the easy dots are located, you are going to have to make some estimates for the next series of dots. For example, the curve almost touches the 1 line as it crosses the E line. Put a dot there and at similar points where the curve crosses other lines.

After you have located all of the points for the curve, sketch a line through all of the points, **Figure 21-30**. Refer to the figure to see how the line should pass through the point. If you are not sure, you can always

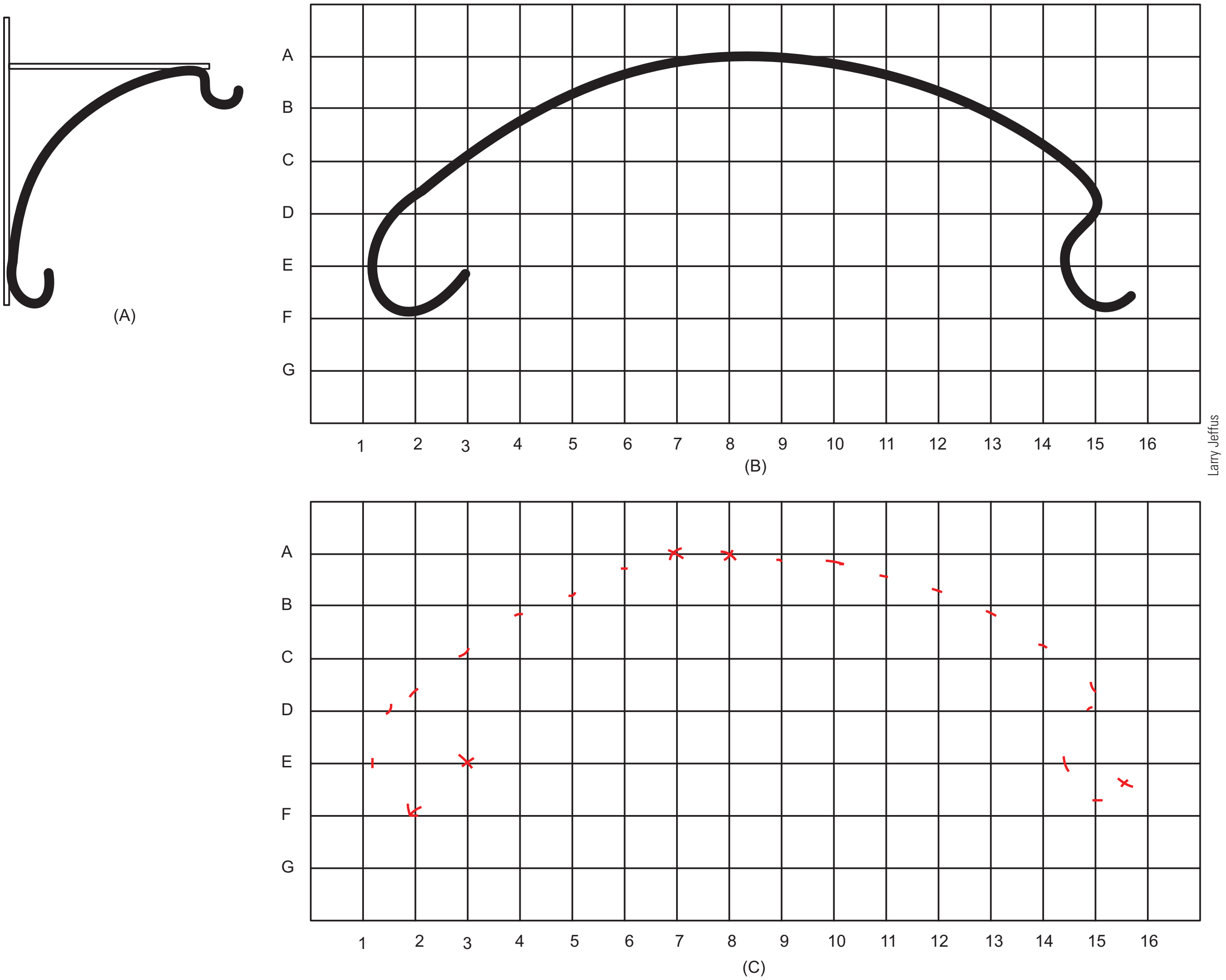

FIGURE 21-29 (A) Practice 21-7: Sketching irregular shapes. (B) Irregular shape laid out on graph paper. (C) Make small marks on a second sheet of graph paper, then connect the dots to copy the irregular shaped curve.

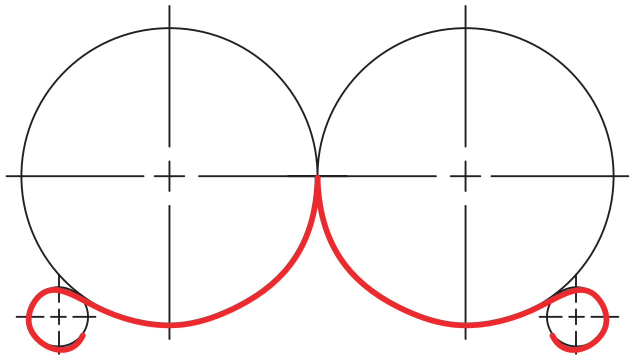

FIGURE 21-30 Circles can be drawn to create some curves.

add additional points that are not on lines to help guide your sketching.

NOTE

The curve you made is called free-form and, as the name implies, it is not an exacting process. If you are working on an exacting curve, there will often be center points for you to follow. You would use a compass to lay out this curve.

Repeat this practice and make a three-view drawing of the candlestick holder shown in **Figure 21-31**. ◆

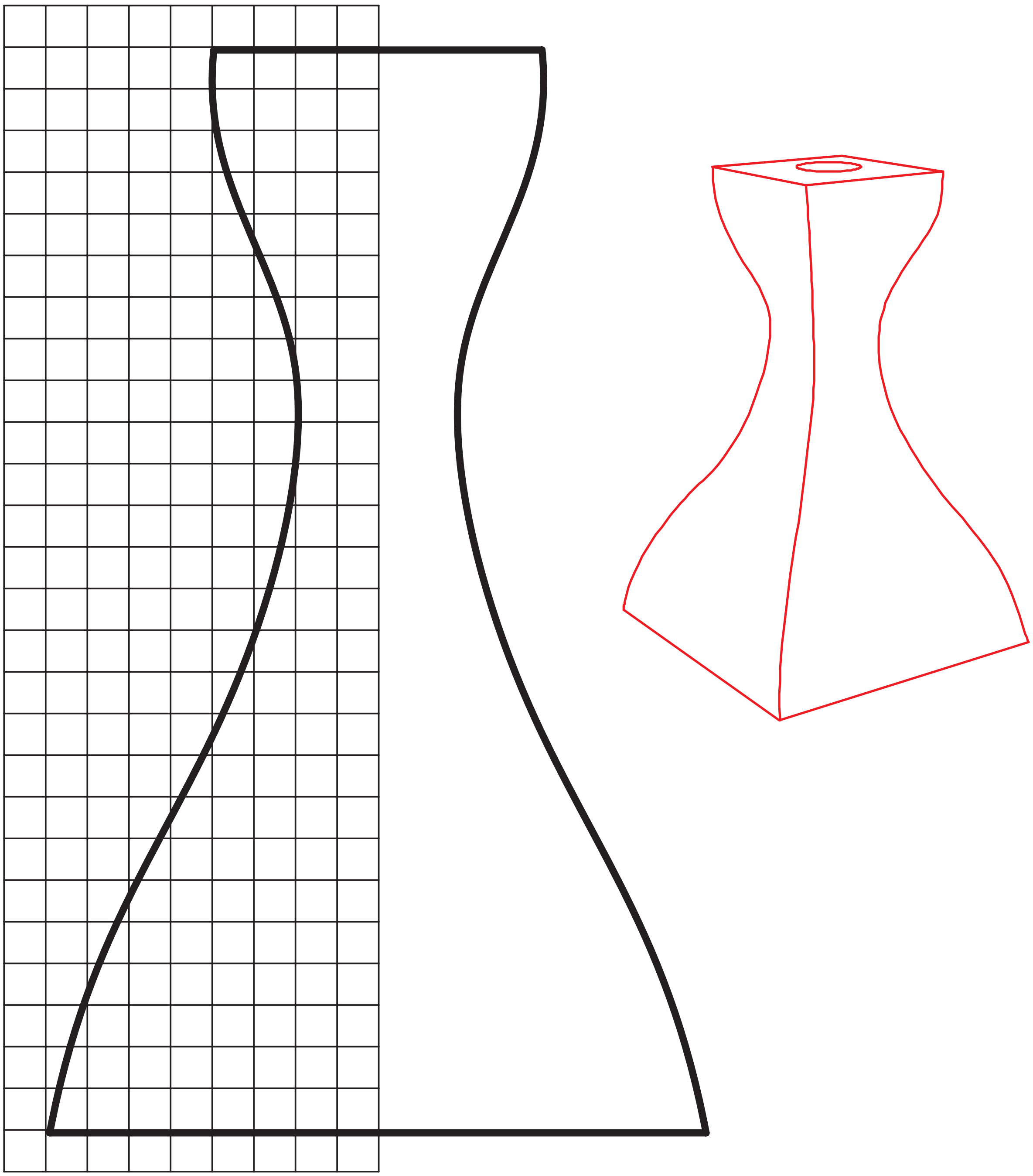

FIGURE 21-31 Practice 21-7: Additional curves to be sketched.

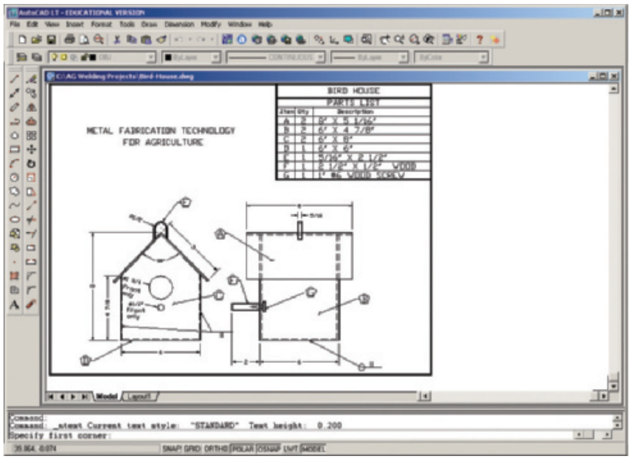

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FIGURE 21-32 AutoCAD LT drafting program used to design a welded project.

COMPUTERS AND DRAWINGS

Computers have made it much easier to draw plans for projects. The welded birdhouse project shown in **Figure 21-32** was drawn on AutoCAD LT. There are a number of apps and computer drawing programs like AutoCAD LT available. Drafting programs that use **vector lines** are different from most other drawing programs, which use raster art. Computers see vector lines as lines, and they see raster lines as if they were part of a picture. Because vector drawings are seen by the computer as lines, you can zoom in and out, measure, resize, reshape, or rotate the drawing and the lines stay crisp and sharp. For example, as the lines on the roof of the vector-drawn birdhouse in **Figure 21-33** are magnified 300 and 500 times, they stay sharp.

Computers see raster images as a series of small squares called pixels. Raster drawings are commonly known as bitmap drawings because the computer maps the location of every little bit (pixel) of the drawing. When these pixels are very small, your eye sees them as a line, but as you zoom in, they start looking like a bunch of colored squares. For example, as the lines on the roof of the bitmap-drawn birdhouse in **Figure 21-34** are magnified 300 and 500 times, they look like a group of colored squares not even recognizable as lines. Bitmap lines have a softer appearance, and they work best in art and photographic programs. The sharp, crisp lines of vector drawings work best for mechanical drawings.

Two-dimensional (2D) drafting programs, like AutoCAD LT, allow you to make mechanical drawings accurately for projects. Vector drafting programs allow you to draw trailers, barns, or other large projects more accurately than they can be built. Using the pull-down and dimensioning options, you could set the precision for this birdhouse drawing at 1/256 in. (0.01 mm), **Figure 21-35**. Accuracy is important when parts must fit together and move without interfering with each other. It is also helpful when planning projects like the trailer in **Figure 21-36**. The back of the trailer has ramps built on it that can be flipped down for easier loading of equipment. The ramps are hinged to the back of the trailer so that when they are in the up position, the dropped back end of the bed is level. AutoCAD LT makes designing the trailer easier, and leveling the bed makes it easier to haul hay, **Figure 21-37**.

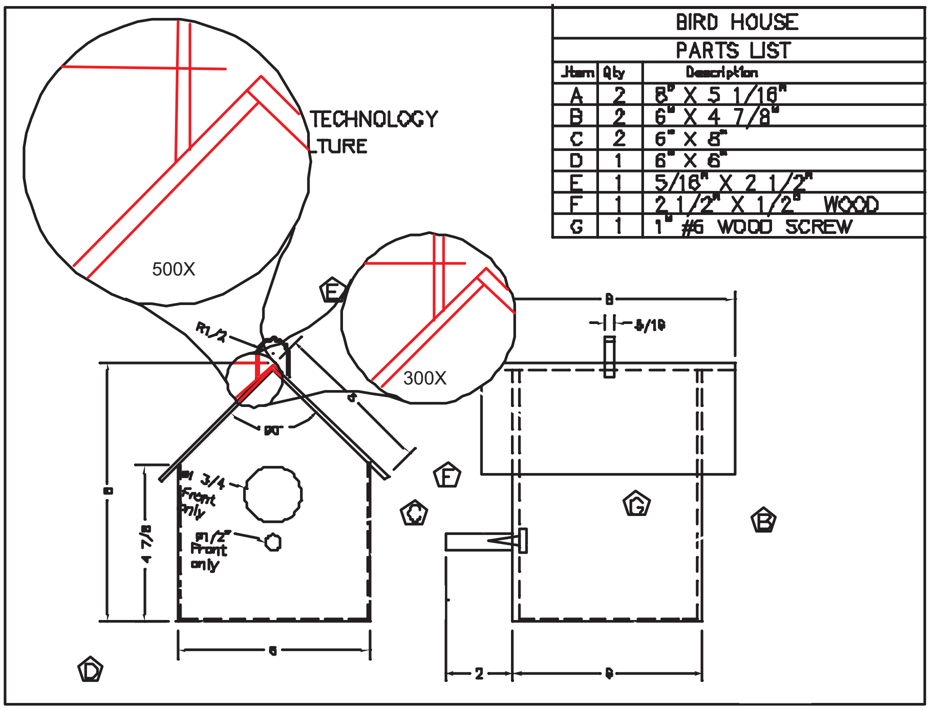

FIGURE 21-33 Vector line art drawing.

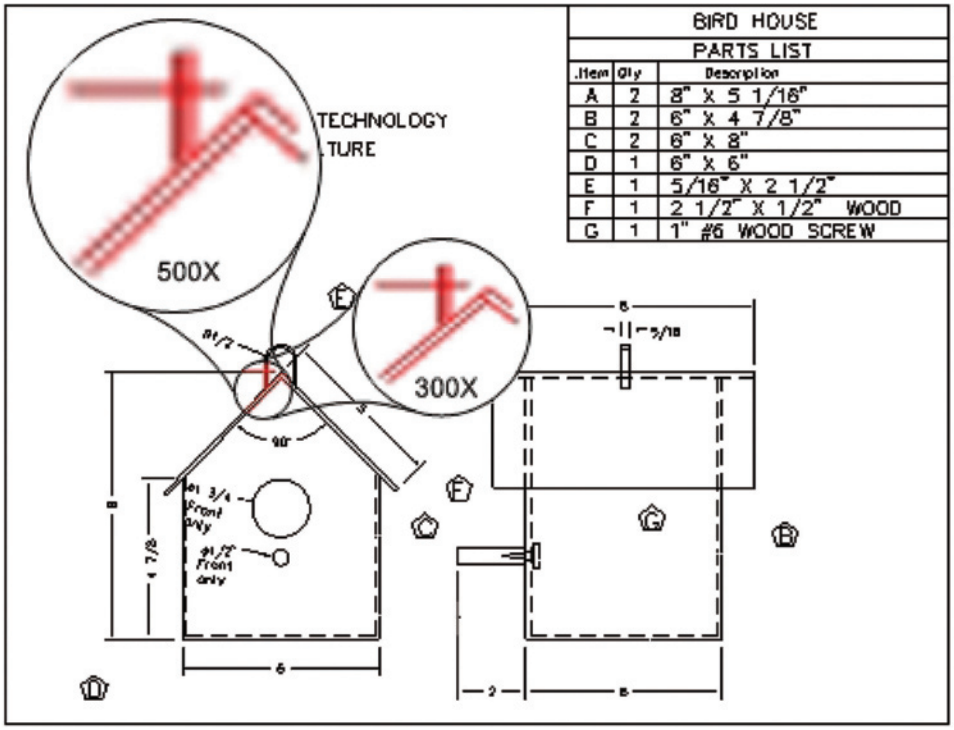

FIGURE 21-34 Bitmap line drawing.

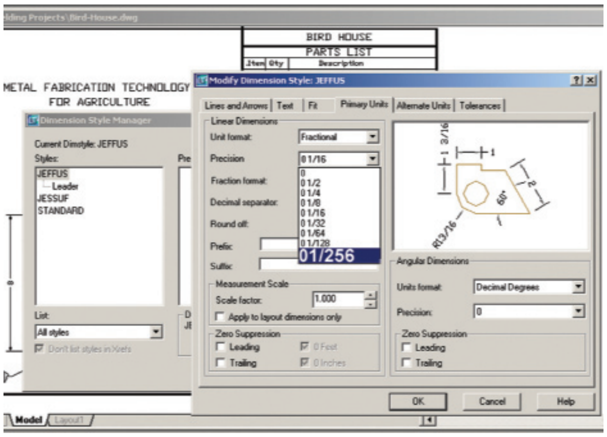

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FIGURE 21-35 The drawing precision can be set on AutoCAD LT using the dimension style manager.

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FIGURE 21-36 Well-designed agricultural trailer for hauling both hay and equipment.

Lines on a mechanical drawing connect to other lines on the drawing. It is that connection between lines that allows the object being drawn to take shape. Very rarely would a mechanical drawing line just be drawn by itself. Computerized drafting programs make it easy to make lines connect. As the cursor nears the end of a line in AutoCAD LT, as with many vector drafting programs, the end of the line changes color, **Figure 21-38**. If you move closer, the line will "jump" to join the end of the first line drawn. This feature of "joining lines," like other features, can be adjusted or turned off as needed. This ability to customize the settings on a drafting program makes the program much easier and faster to use.

The readability and ease of understanding a drawing is dependent on the drawing's layout and location of dimensions and notes. Drafting programs allow you to move things around to make them clearer and easier to understand. This feature is important because on pencil drawings, erasing and redrawing can result in a messy drawing, which can make it harder to understand.

On-screen help with computer drafting is available in several general ways. One method of getting on-screen help is by hovering the curser over a function button and a one- or two-word description of the button will appear, **Figure 21-39**. A more complete listing of help is available by clicking the "?" button on the tool bar at the top of the screen, **Figure 21-40**. Some programs like AutoCAD LT provide an Active Assistant that pops up the first time a function button is clicked, **Figure 21-41**. The Active Assistant provides step-by-step instructions on how to use that function.

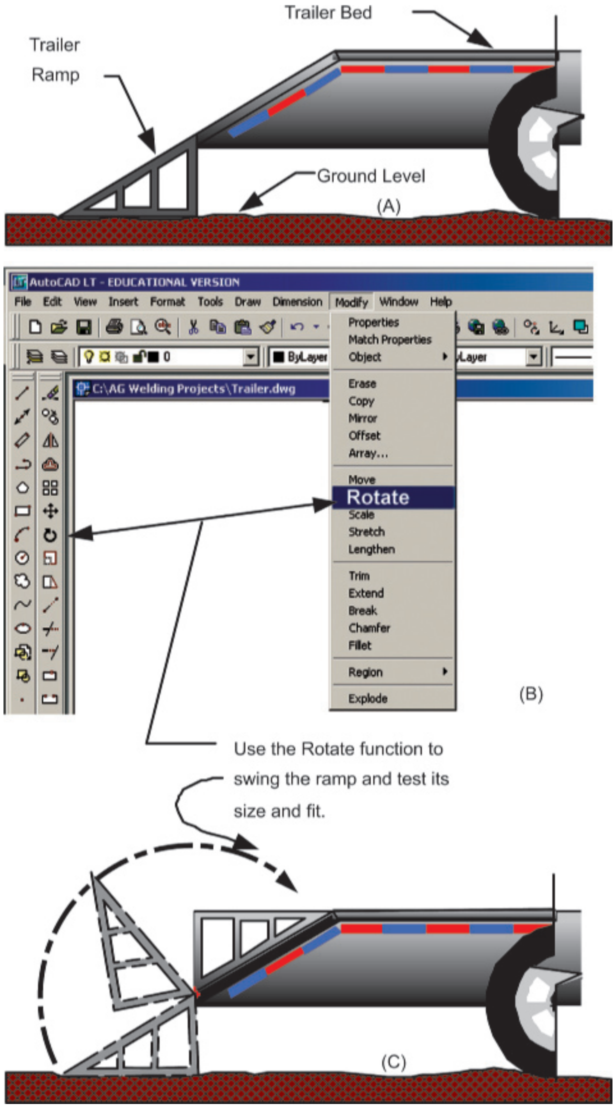

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FIGURE 21-37 The AutoCAD LT rotate feature can be used to check part alignment and fit, such as the trailer ramp on this drawing.

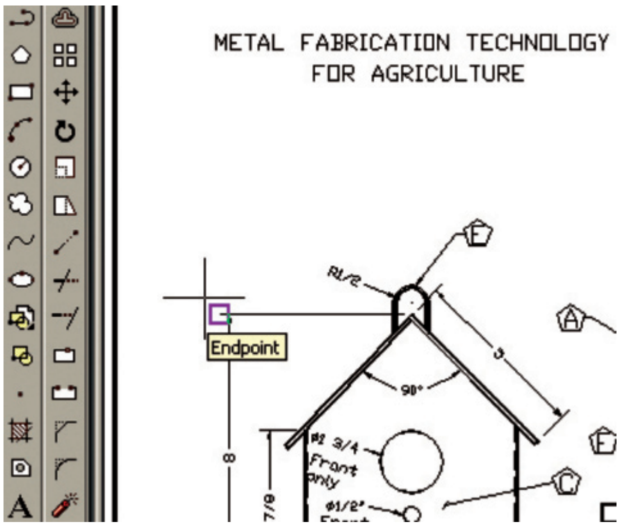

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FIGURE 21-38 The AutoCAD LT makes it easy to connect lines with its endpoints connecting feature.

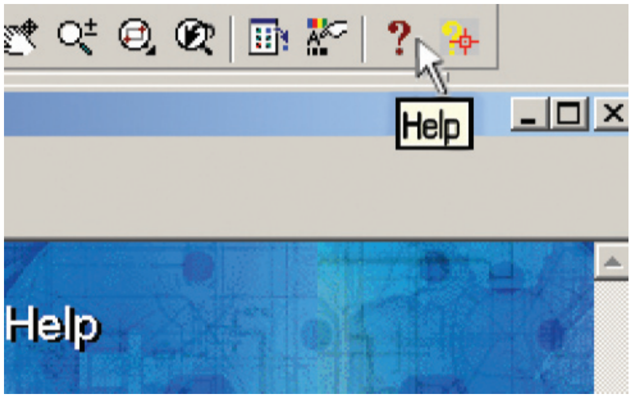

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FIGURE 21-39 Hovering above an icon will provide a one- or two-word hint.

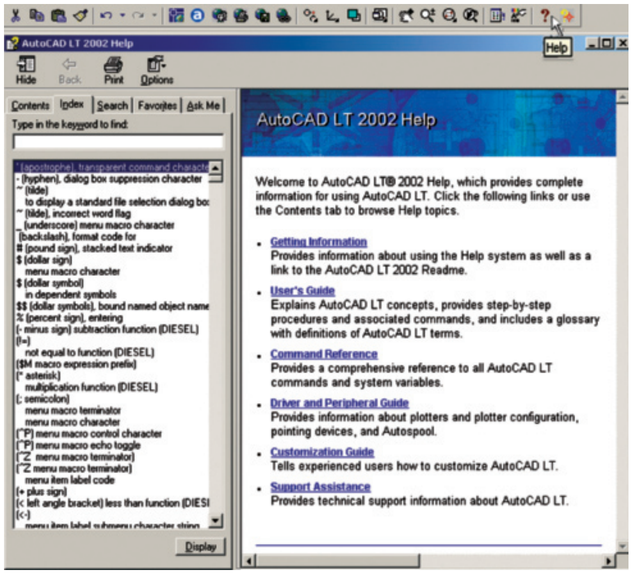

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FIGURE 21-40 On-screen help will guide you through many of the computer program's features.

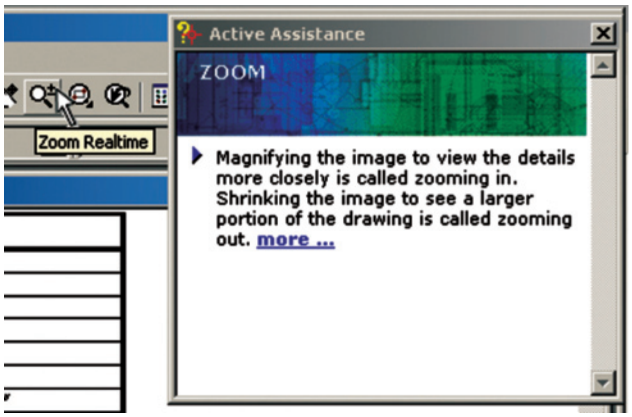

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FIGURE21-41 Active Assistant details the specific functions available.

Summary

Almost every welding fabrication will have a set of drawings detailing exactly how the assembly is to be made. Welders who can read and accurately follow these drawings have a skill that is valuable to any welding shop. Even the slightest error in the measuring, cutting, placing, or welding of the fabrication can cause it to be scrapped or necessitate expensive reworking.

All welders need to have a good understanding and working knowledge of mechanical drawings even if they are not directly involved with fabricating parts. Even though you may not have been the one to assemble the weldment, you should still be able to do a quick check to see that it was assembled according to the drawings.

Review

1. Give examples of drawing pages that might be included in a set of drawings.
2. The title box on a drawing can contain what information?
3. Where would a welder look in the set of drawings to find a list of the various items that would be needed to build a weldment?
4. Sketch an object that contains all of the necessary elements so that you can use the following line types: object line, hidden line, centerline, extension line, and dimension line. Label each line type using leaders and arrows.
5. What type of lines can be used in a drawing to show that part of an object has been removed?
6. Describe what phantom lines are in a drawing.
7. Compare an orthographic projection (mechanical drawing) to a pictorial drawing.
8. A mechanical drawing usually includes which three views of an object?
9. List two types of pictorial drawings that can be included with a set of mechanical drawings.
10. What view might be used to show part of an object as if it were sawn away to reveal internal details?
11. What kind of information does a detail view on a drawing provide?
12. The height of an object would be found on which of the standard views in a set of drawings?
13. What is the difference between "as drawn" and "as built" drawings?
14. What tool can be used to draw an object so that it is smaller or larger than it really is?
15. What is the difference between architectural scales and engineering scales?
16. Why is knowing how to sketch a drawing a valuable skill in the welding shop?
17. Which type of computer graphics program lines stay crisp and clean no matter how much you zoom in and out of the image?

Chapter 22

Welding Joint Design and Welding Symbols

OBJECTIVES

After completing this chapter, the student should be able to

- understand the basics of joint design.
- list the five major types of joints.
- list seven types of weld grooves.
- identify the major parts of a welding symbol.
- explain the parts of a groove preparation.
- describe how nondestructive test symbols are used.

KEY TERMS

combination symbol

edge preparation

fillet (F)

grooves (G)

joint dimensions

joint types

weld joint

weld location

weld types

welding symbols

INTRODUCTION

Each joint's design affects the quality and cost of the completed weld. Selecting the most appropriate joint design for a welding job requires special attention and skill. The eventual design selection can be influenced by a number of factors.

Every weld joint selected for a job requires some compromises. For example, the compromises may be between strength and cost, equipment available, and welder skill, or any two, three, or more variables. Because there are so many factors, a good design requires experience. Even with experience, trial welds are necessary before selecting the final joint configuration and welding parameters.

This chapter familiarizes welders with the most important factors and gives them some appreciation of joint design and fabrication. Experience in the welding field will help a welder become a better joint designer and fabricator.

Welding symbols are the language used to let the welder know exactly what welding is needed. The welding symbol is used as shorthand and can provide the welder with all of the required information to make the correct weld. The emphasis in this chapter is on using and interpreting welding symbols so the welder will develop a welder's "vocabulary."

WELD JOINT DESIGN

The term *weld joint design* refers to the way pieces of metal are put together or aligned with each other. The five basic joint designs, or **joint types**, are butt joints, lap joints, tee joints, outside corner joints, and edge joints. **Figure 22-1** illustrates the way the joint members come together:

- Butt joint—In a butt joint, the edges of the metal meet so that the thickness of the joint is approximately equal to the thickness of the metal. The metal surfaces are usually parallel with each other, although there can be some difference in thickness and/or misalignment of the plates. Butt joints can be welded from one side or both sides with some form of groove weld.
- Lap joint—In a lap joint, the edges of the metal overlap so the thickness of the joint is approximately equal to the combined thickness of both pieces of metal. The distance the surfaces overlap each other may vary from a fraction of an inch to several inches or even feet. Lap welds are usually joined by making a fillet weld along the edge of one plate joining it to the surface of the other. There are several alternate ways of welding lap joints where the weld is made through one or both pieces of metal joining the lap in the center of the overlap. Some examples of this would be plug welds and seam welds. Welds can be made on one side or both sides of the joint.
- Tee joint—In a tee joint, the edge of a piece of metal is placed on the surface of another piece of metal. Usually the parts are placed at a 90° angle with each other. Tee joints can be welded with a fillet weld applied to the surfaces or a weld can be made in a precut groove in the edge of the joining plate. In a few cases, a fillet weld can be made on top of a groove weld on a tee joint. Welds can be made on one side or both sides of the joint.
- Outside corner joint—In an outside corner joint the edges of the metal are brought together at an angle, usually approximately 90° to each other. The edges can meet at the corner evenly or they can overlap, **Figure 22-2**. The outside corner joint can be welded on both sides, with the outside being made as a groove weld and the inside being made as a fillet weld.
- Edge joint—In an edge joint, the metal surfaces are placed together so that the edges are even. One or both plates may be formed by bending them at an angle, **Figure 22-3**. Edge joints are usually welded on only one side.

Welding drawings and specifications usually tell you exactly which joint design will be used for all of the welds to be made. Often a welding engineer or designer has determined the best type of joint to be used. However, on small projects or on some repair welding jobs you will be making the decision regarding what joint design should be used. The way the pieces of metal fit together may determine the joint design that must be used. For example, the part shown in **Figure 22-4** can only be made using tee joints. Joints on every weldment are not as easily determined.

If you are the one choosing the weld joint design, then you must consider a number of factors. Some of the factors involve the type and thickness of metal being welded, the welding position, the welding process, finished weld properties, and any code requirements. The selection of the best joint design for a specific weldment requires that you carefully consider all of the various factors. Each factor, if considered alone, could result in a part that might not be

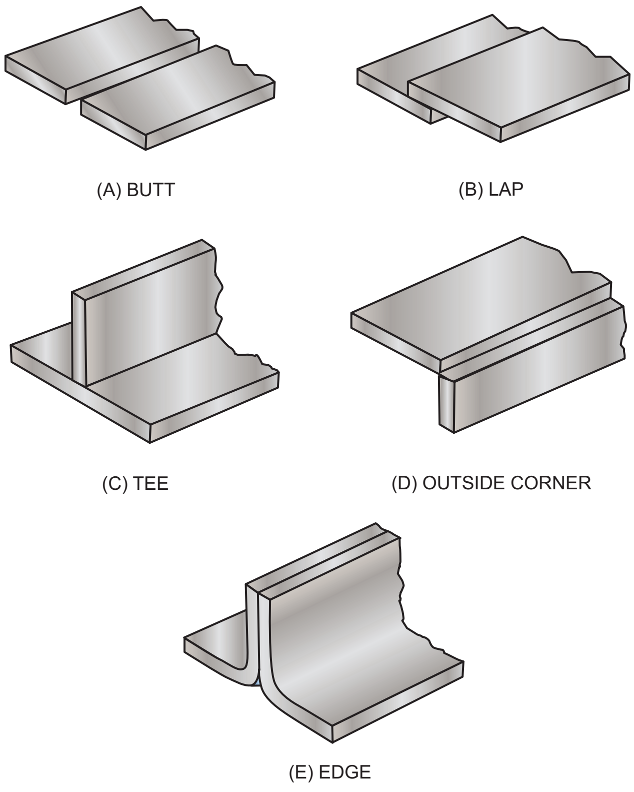

FIGURE 22-1 Types of joints.

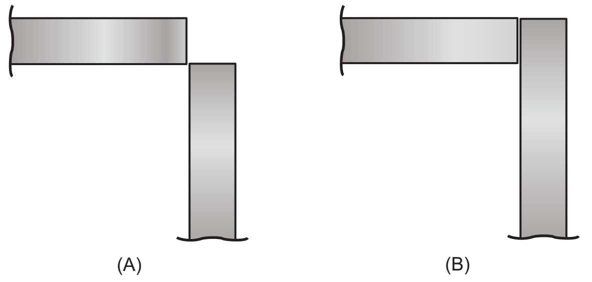

FIGURE 22-2 Two ways of fitting up an outside corner joint (A) so it forms a V-groove or (B) so it forms a square butt joint.

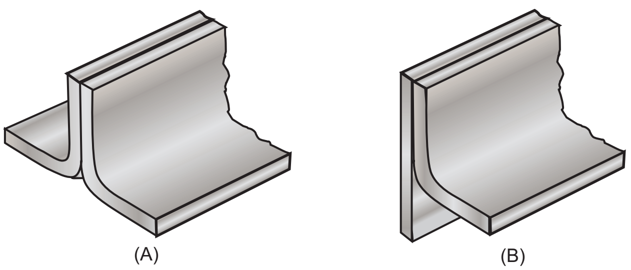

FIGURE 22-3 Edge joints.

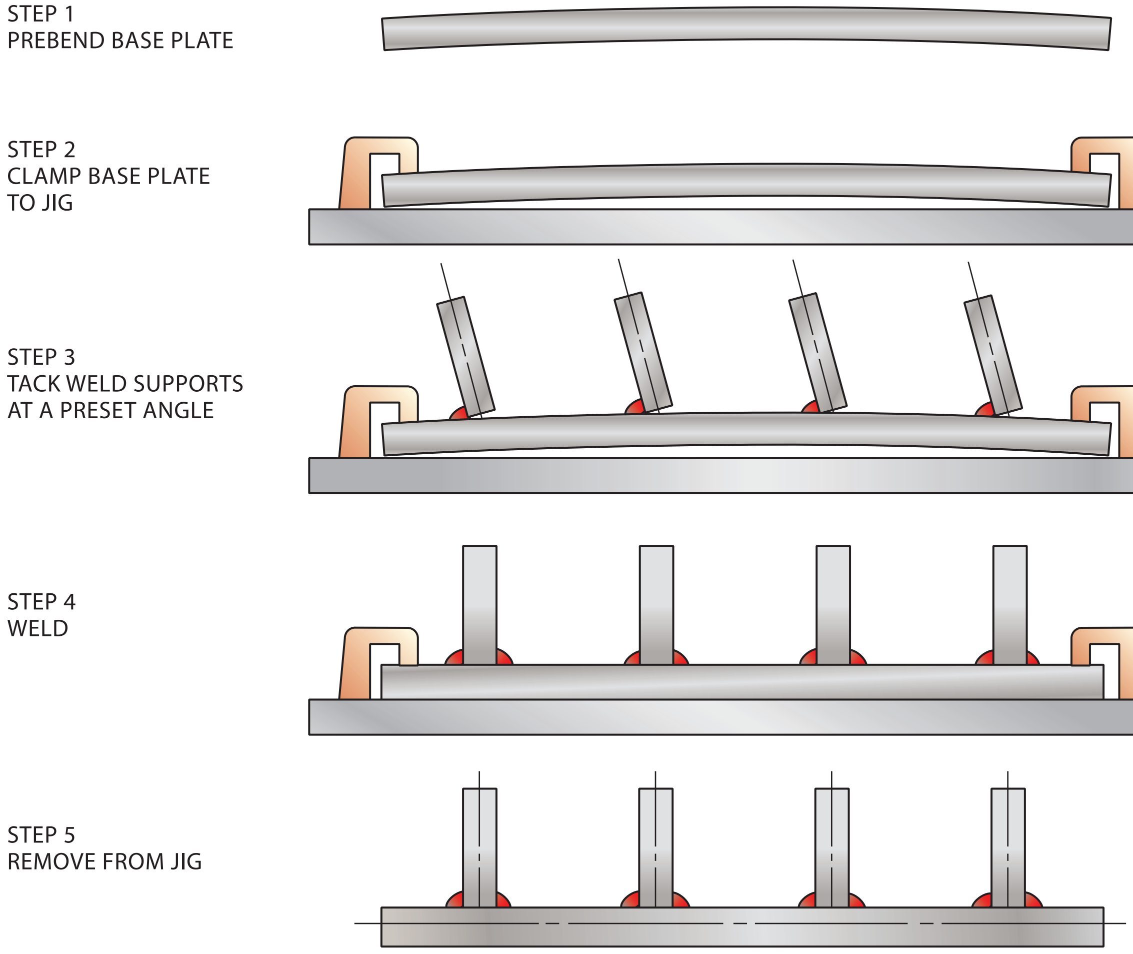

FIGURE 22-4 A method of controlling distortion.

able to be fabricated or might not meet the strength requirements. For example, a narrower joint angle requires less filler metal, and that results in lower welding cost. But if the angle is too small for the welding process being used, then the weld cannot be made strong enough. A large weld may be stronger, but it may result in the part being distorted so badly that it becomes useless.

Weld Joint Stresses

The purpose of a **weld joint** is to join parts together so that the stresses are distributed. The forces causing stresses in welded joints are tensile, compression, bending, torsion, and shear, **Figure 22-5**. The ability of a welded joint to withstand these forces depends on both the joint design

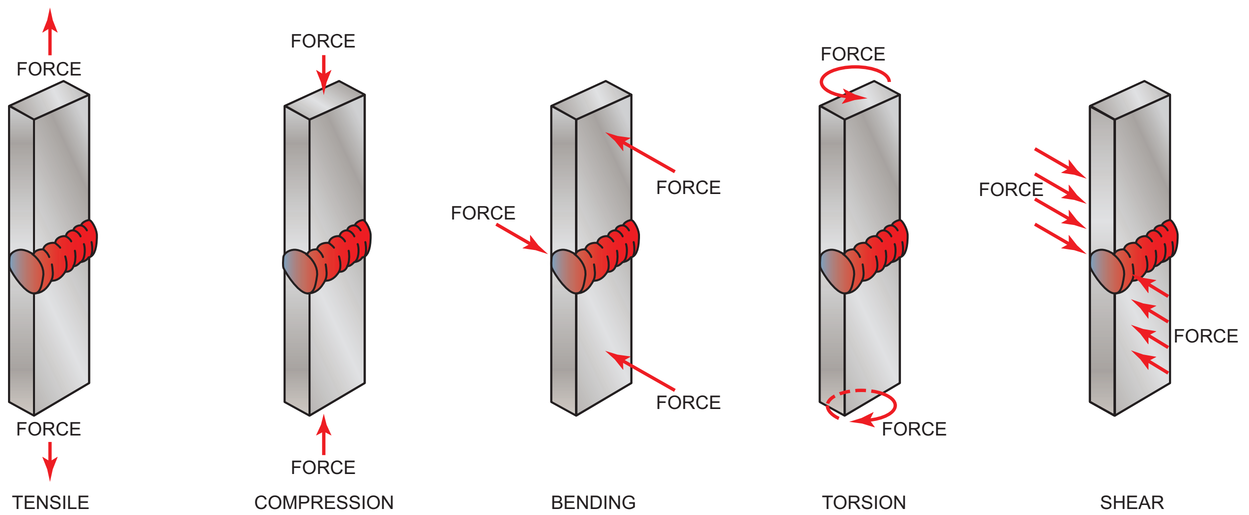

FIGURE 22-5 Forces on a weld.

and the weld integrity. Some joints can withstand some types of forces better than others.

Welding Process

The welding process to be used has a major effect on the selection of the joint design. Each welding process has characteristics that affect its performance. Some processes are easily used in any position; others may be restricted to one or more positions. The rate of travel, penetration, deposition rate, and heat input also affect the welds used on some joint designs. For example, a square butt joint can be made in very thick plates using either electroslag or electrogas welding, but not many other processes can be used on such a joint design.

Edge Preparation

The area of the metal's surface that is melted during the welding process is called the *faying surface*. The faying surface can be shaped before welding to increase the weld's strength; this is called **edge preparation**. The edge preparation may be the same on both members of the joint, or each side can be shaped differently, **Figure 22-6**. Reasons for preparing the faying surfaces for welding include the following:

- Codes and standards—Some codes and standards require specific edge preparations.
- Metals—To successfully weld some metals, they must be grooved, such as thick magnesium, which must be U-grooved, or cast-iron cracks, which must be drill stopped and grooved, **Figure 22-7**.
- Deeper weld penetration—With the metal removed by grooving or beveling the metal's edge, it is easier for the molten weld metal to completely fuse through the joint. In some cases it is possible to make a through thickness weld from one side.
- Smooth appearance—The weld's surface can be ground smooth with the base metal so that the weld "disappears." This can be done for appearance or so that the weld does not interfere with the sliding or moving of parts along the surface.
- Increased strength—A weld should be as strong as or stronger than the base metal being joined. By having 100% joint fusion and an appropriate amount of weld reinforcement, the weld can meet its strength requirement.

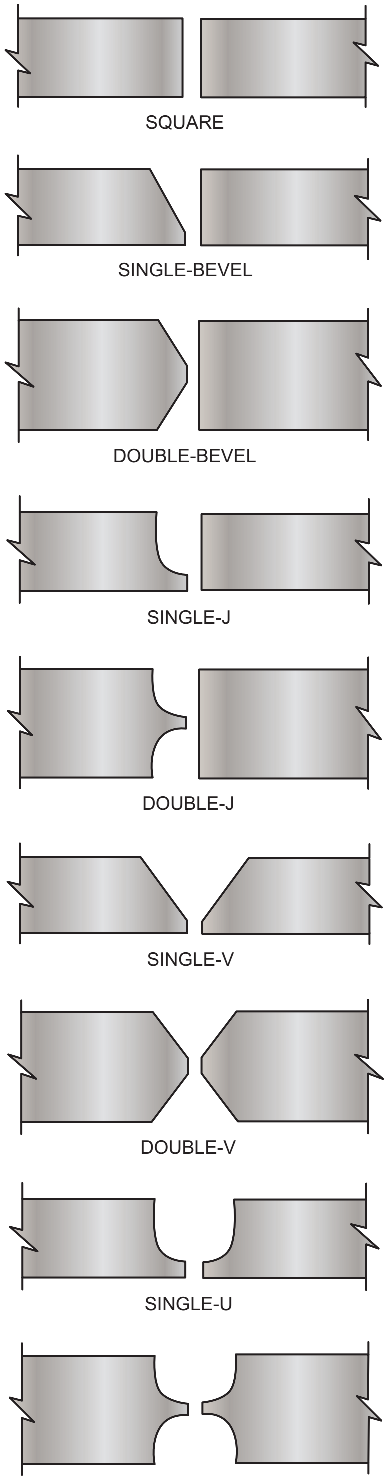

FIGURE 22-6 Joint edge preparation.

JOINT DIMENSIONS

In some cases, the exact size, shape, and angle can be specified for a groove, **Figure 22-8**. If exact dimensions are not given, then you may make the groove any size you feel necessary; but remember, the wider the groove, the more welding it will require to complete.

Metal Thickness

As the metal becomes thicker, you must change the joint design to ensure a sound weld. On thin sections it is often possible to make full penetration welds using a square butt joint. Square butt joints take less preparation time and less welding time. But with thicker plates or pipe, the edge must be prepared with a groove on one or both sides. The edge may be shaped with a bevel, V-groove, J-groove, or U-groove.

When welding on thick plate or pipe, it is often impossible for the welder to get 100% penetration without

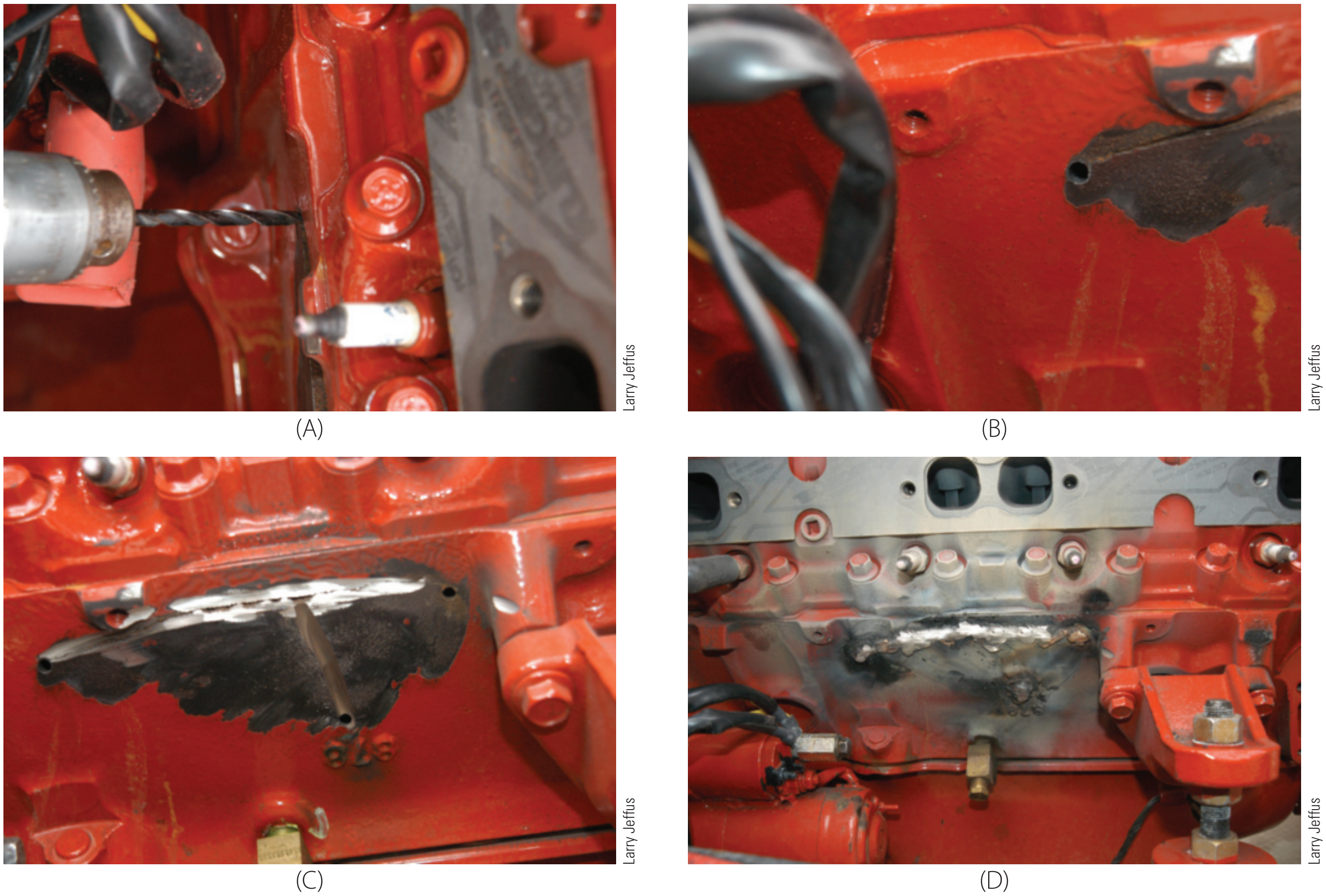

FIGURE 22-7 Steps used to repair a cast iron crack. (A) Drill each end of the crack. (B) The drill hole will stop the crack from lengthening as it is being repaired. (C) Grind a U-groove all the way along the crack. (D) Grind the weld before finishing.

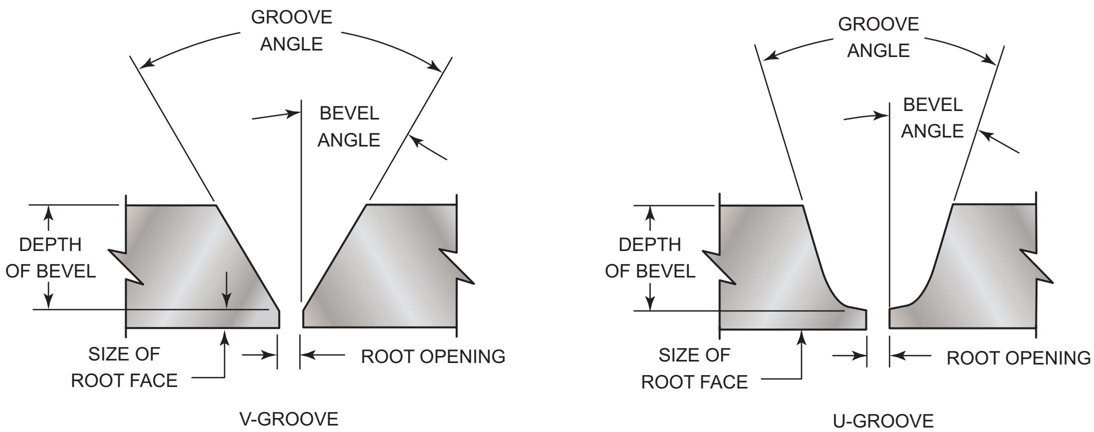

FIGURE 22-8 Groove joint terminology.

some type of groove being used. The groove may be cut into either just one of the plates or pipes or both. On some plates it can be cut both inside and outside of the joint. The groove may be ground, flame cut, gouged, sawed, or machined on the edge of the plate before or after the assembly. Bevels and V-grooves are best if they are cut before the parts are assembled, **Figure 22-9**. J-grooves and U-grooves can be cut either before or after assembly, **Figure 22-10**. The lap joint is seldom prepared with a groove because little or no strength can be gained by grooving this joint.

For most welding processes, plates that are thicker than 3/8 in. (10 mm) may be grooved on both the inside and outside of the joint. A plate in the flat position is usually grooved on only one side, unless it can be repositioned or it is required to be welded on both sides. Tee joints in a

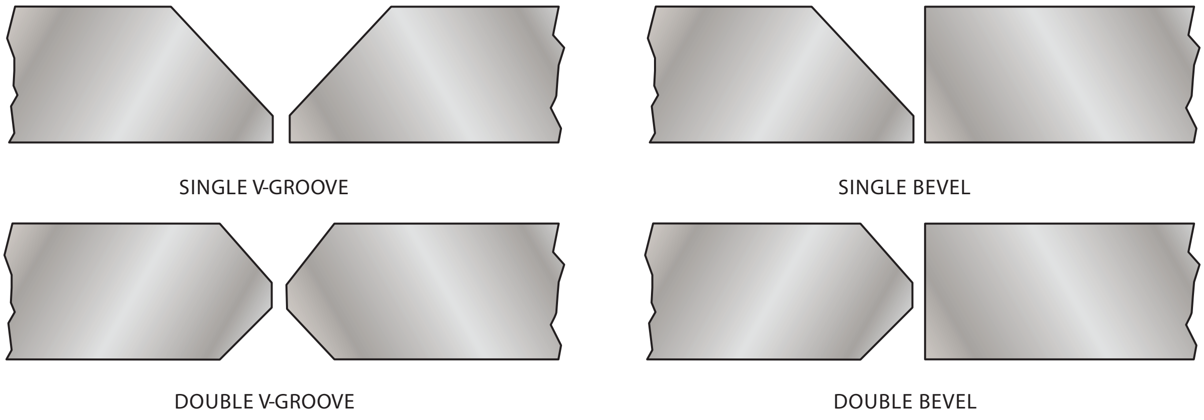

FIGURE 22-9 V-groove and bevel joint types.

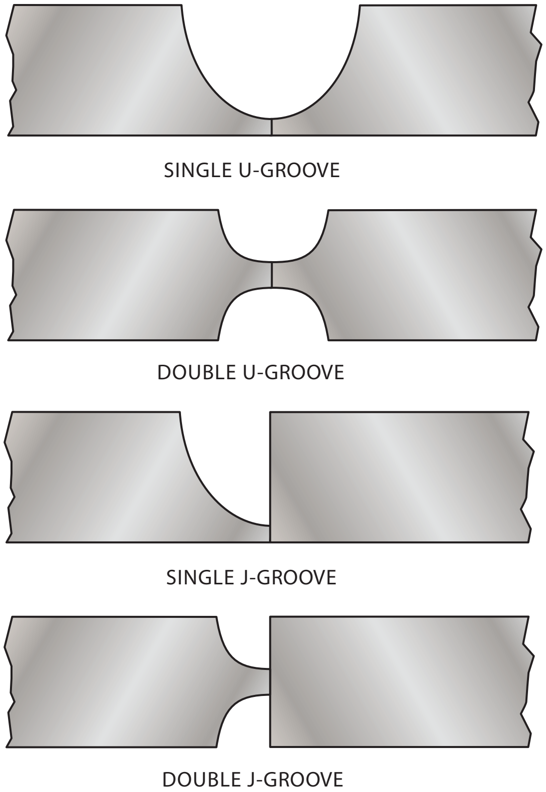

FIGURE 22-10 U-groove and J-groove joint types.

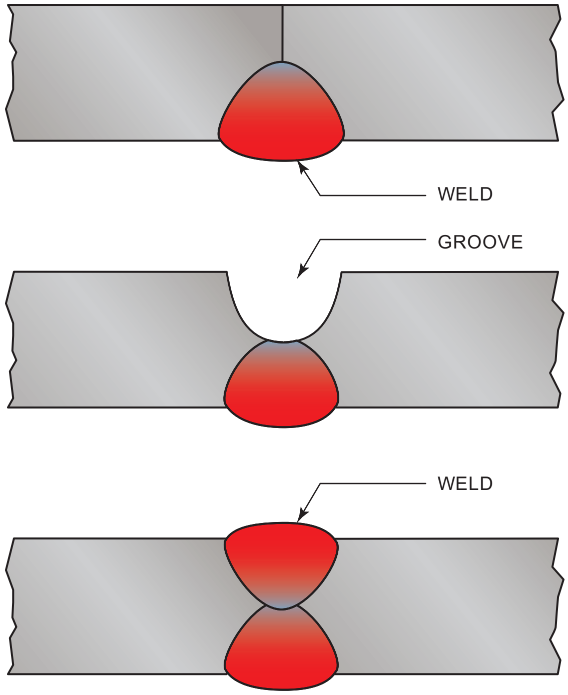

FIGURE 22-11 Back gouging a weld joint to ensure 100% joint penetration.

thick plate are easier to weld and will have less distortion if they are grooved on both sides.

Sometimes plates are either grooved and welded or just welded on one side and then back gouged and welded, **Figure 22-11**. Back gouging is a process of cutting a groove in the back side of a joint that has been welded. Back gouging can ensure 100% joint fusion at the root and can remove discontinuities of the root pass.

Metal Type

Because some metals have specific problems with thermal expansion, crack sensitivity, or distortion, the joint design selected must help control these problems. For example, magnesium is very susceptible to postweld stresses, and the U-groove works best for thick sections.

WELDING POSITION

The most ideal welding position for most joints is the flat position because it allows for larger molten weld pools to be controlled. Usually, the larger that a weld pool can be, the faster the joint can be completed. When welds are made in any position other than the flat position, they are referred to as being done *out of position*. Some types of grooves work better in out-of-position welding than others; for example, the bevel joint is often the best choice for horizontal butt welding, **Figure 22-12**.

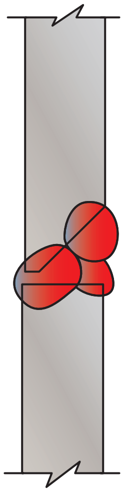

FIGURE 22-12 Weld position for a horizontal joint.

Plate Welding Positions

The American Welding Society (AWS) has divided plate welding into four basic positions for **grooves (G)** and **fillet (F)** welds as follows:

- Flat 1G or 1F—When welding is performed from the upper side of the joint and the face of the weld is approximately horizontal, **Figure 22-13A** and **B**.
- Horizontal 2G or 2F—The axis of the weld is approximately horizontal, but the type of the weld dictates the complete definition. For a fillet weld, welding is performed on the upper side of an approximately vertical surface. For a groove weld, the face of the weld lies in an approximately vertical plane, **Figure 22-13C** and **D**.
- Vertical 3G or 3F—The axis of the weld is approximately vertical, **Figure 22-13E** and **F**.
- Overhead 4G or 4F—When welding is performed from the underside of the joint, **Figure 22-13G** and **H**.

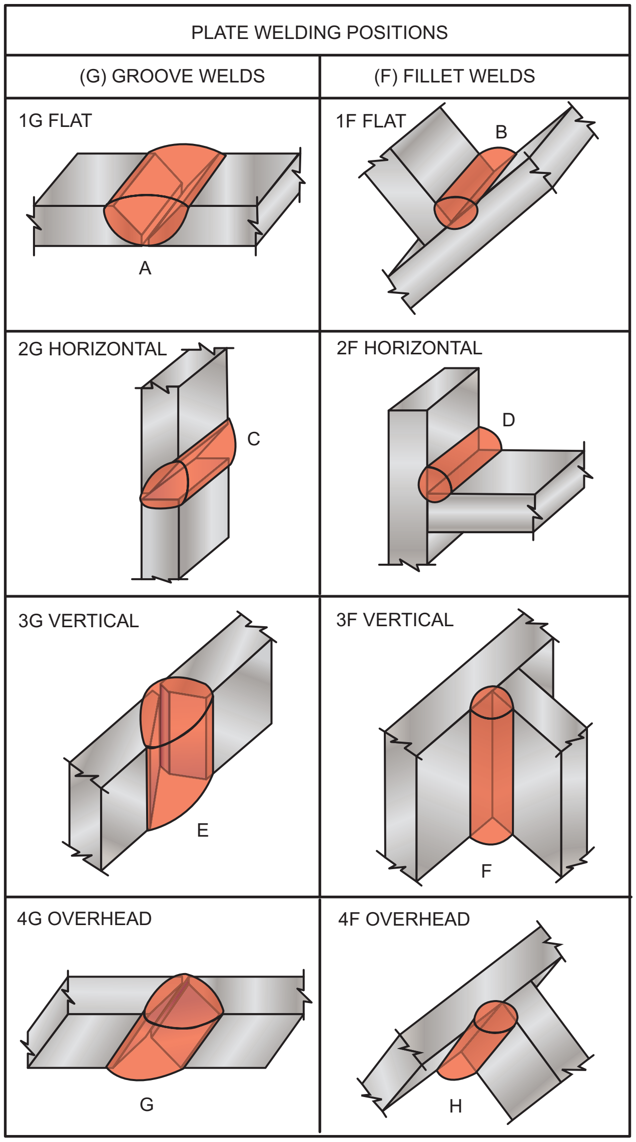

FIGURE 22-13 Plate welding positions.

Pipe Welding Positions

The American Welding Society has divided pipe welding into five basic positions:

- Horizontal rolled 1G—The pipe is rolled either continuously or intermittently so that the weld is performed within 0° to 15° of the top of the pipe, **Figure 22-14A**.
- Horizontal fixed 5G—The pipe is parallel to the horizon, and the weld is made vertically around the pipe, **Figure 22-14B**.
- Vertical 2G—The pipe is vertical to the horizon, and the weld is made horizontally around the pipe, **Figure 22-14C**.
- Inclined 6G—The pipe is fixed in a 45° inclined angle, and the weld is made around the pipe, **Figure 22-14D**.
- Inclined with a restriction ring 6GR—The pipe is fixed in a 45° inclined angle, and there is a restricting ring placed around the pipe below the weld groove, **Figure 22-14E**.

CODE OR STANDARDS REQUIREMENTS

The type, depth, angle, and location of the groove are usually determined by a code or standard that has been qualified for the specific job. Organizations such as the American Welding Society, the American Society of Mechanical Engineers (ASME), and the American Bureau of Ships (ABS) are among the agencies that issue such codes and specifications. The most common code or standards are the AWS D1.1 and the ASME Boiler and Pressure Vessel (BPV), Section IX.

The joint design for a specific set of specifications often must be what is known as prequalified. These joints have

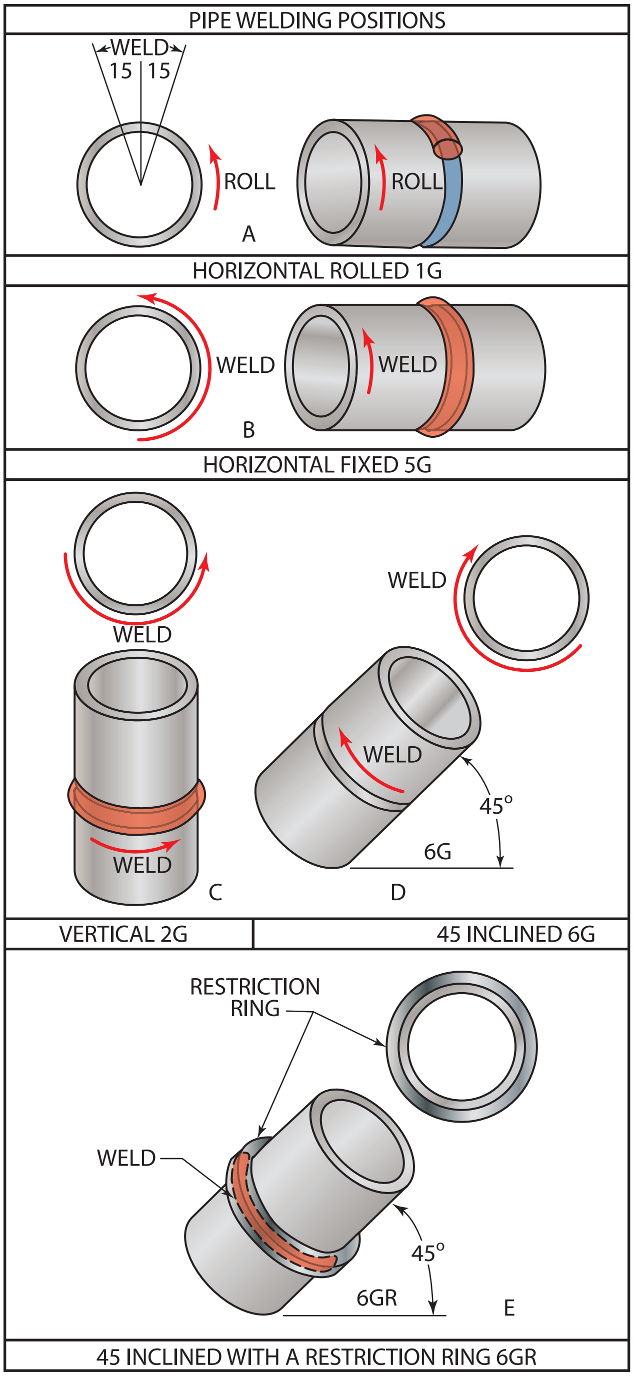

FIGURE 22-14 Pipe welding positions.

been tested and found to be reliable for the weldments for specific applications. The joint design can be modified, but the cost to have the new design accepted under the standard being used is often prohibitive.

Welder Skill

Often the skills or abilities of the welder are a limiting factor in joint design. A joint must be designed in a manner so that the welders can reliably reproduce it. Some joints have been designed without adequate room for the welder

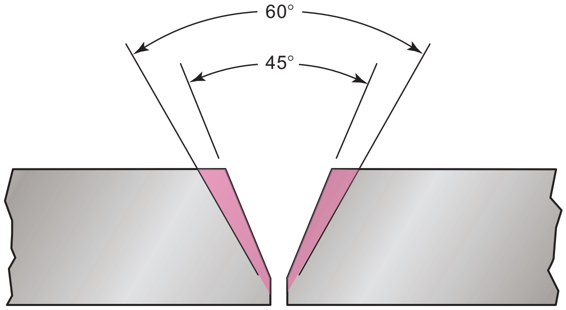

FIGURE 22-15 A smaller groove angle reduces both weld time and weld metal.

to see the molten weld pool or room to get the electrode or torch into the joint.

Acceptable Cost

Almost any weld can be made in any material in any position. A number of factors can affect the cost of producing a weld. Joint design is one major way to control welding cost. Changes in the design can reduce cost yet still meet the weldment's strength requirements. Reducing the groove angle can also help, **Figure 22-15**. It will decrease the welding filler metal required to complete the weld as well as decrease the time required to fill the larger groove opening. Joint design must be a consideration for any project to be competitive and cost-effective.

WELDING SYMBOLS

The use of welding symbols enables a designer to indicate clearly to the welder important detailed information regarding the weld. The information in the welding symbol can include the following details for the weld: length, depth of penetration, height of reinforcement, groove type, groove dimensions, location, process, filler metal, strength, number of welds, weld shape, and surface finishing. All this information would normally be included on the welding assembly drawings.

Welding symbols are a shorthand language for the welder. They save time and money and serve to ensure understanding and accuracy. Welding symbols have been standardized by the American Welding Society. Some of the more common symbols for welding are represented in this chapter. If more information is desired about symbols or how they apply to all forms of manual and automatic machine welding, then these symbols can be found in the complete manual *Standard Symbols for Welding, Brazing and Nondestructive Examination*, ANSI/AWS A2.4, published as an American National Standard by the American Welding Society.

Figure 22-16 shows the basic components of welding symbols, consisting of a reference line with an arrow on one end. Other information relating to various features of the weld is shown by symbols, abbreviations, and figures located around the reference line. A tail is added to the basic symbol as necessary for the placement of specific information.

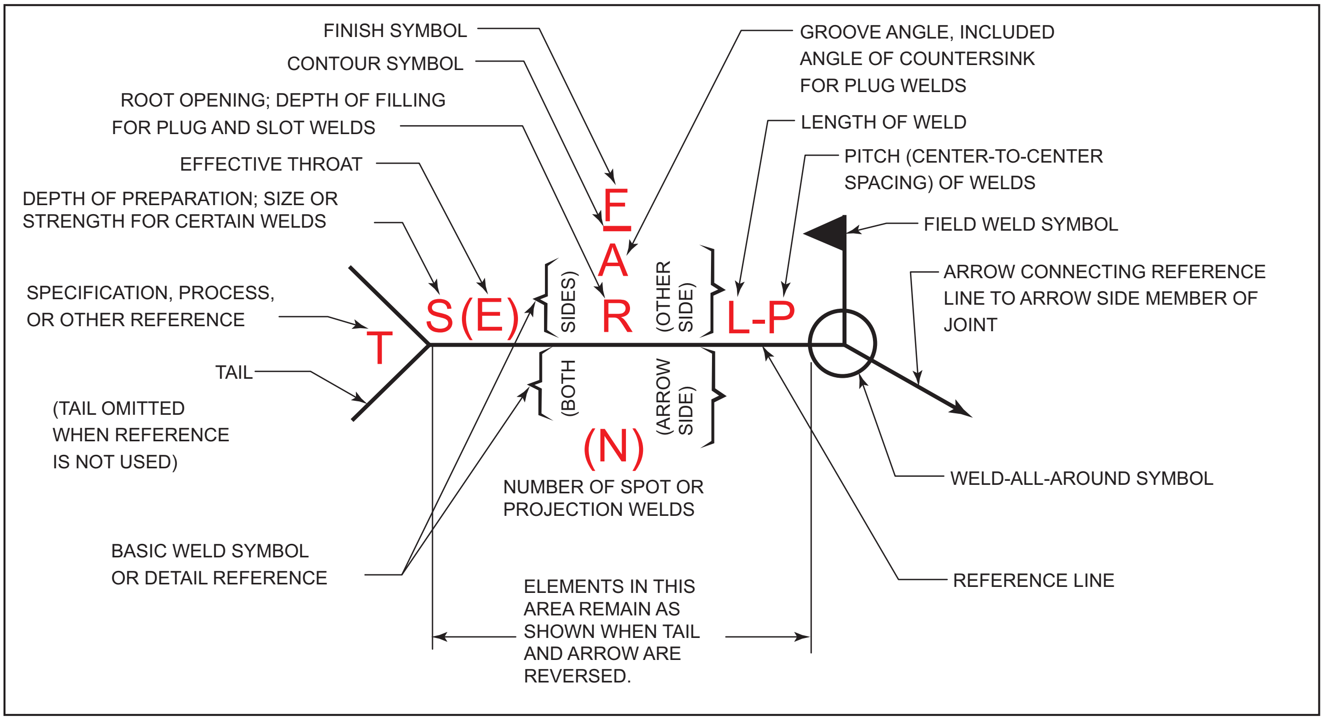

FIGURE 22-16 Standard location of elements of a welding symbol.

Indicating Types of Welds

Weld types are classified as follows: fillets, grooves, flange, plug or slot, spot or projection, seam, back or backing, and surfacing. Each type of weld has a specific symbol that is used on drawings to indicate the weld. A fillet weld, for example, is designated by a right triangle. A plug weld is indicated by a rectangle. All of the basic symbols are shown in **Figure 22-17**.

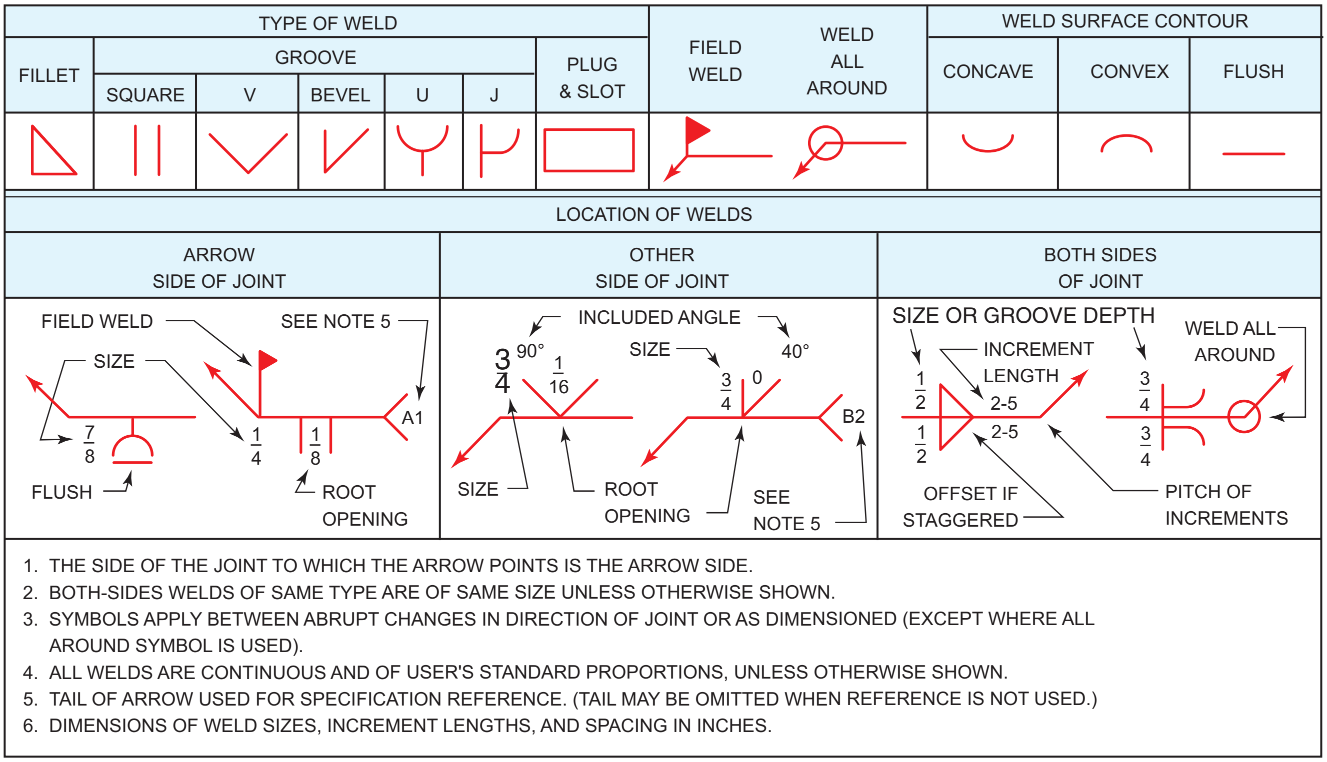

FIGURE 22-17 Welding symbols for different types of welds.

Weld Location

Welding symbols are applied to the joint as the basic reference. All joints have an arrow side (near side) and other side (far side). Accordingly, the terms *arrow side*, *other side*, and *both sides* are used to indicate the **weld location** with respect to the joint. The reference line is always drawn horizontally. An arrow line is drawn from one end or both ends of a reference line to the location of the weld. The arrow line can point to either side of the joint and extend either upward or downward.

If the weld is to be deposited on the arrow side of the joint (near side), then the proper weld symbol is placed below the reference line, **Figure 22-18A**.

If the weld is to be deposited on the other side of the joint (far side), then the weld symbol is placed above the reference line, **Figure 22-18B**. When welds are to be deposited on both sides of the same joint, the same weld symbol appears above and below the reference line, **Figure 22-18C** and **D**, along with all detailed information.

The tail is added to the basic welding symbol when it is necessary to designate the welding specifications, procedures, or other supplementary information needed to make the weld, **Figure 22-19**. The notation placed in the tail of the symbol may indicate the welding process to be used, the type of filler metal needed, whether or not peening or root chipping is required, and other information pertaining to the weld. If notations are not used, then the tail of the symbol is omitted.

For joints that are to have more than one weld, a symbol is shown for each weld.

Location Significance of Arrow

In the case of fillet and groove welding symbols, the arrow connects the welding symbol reference line to one side of the joint. The surface of the joint the arrow point actually touches is considered to be the arrow side of the joint. The side opposite the arrow side of the joint is considered to be the other (far) side of the joint.

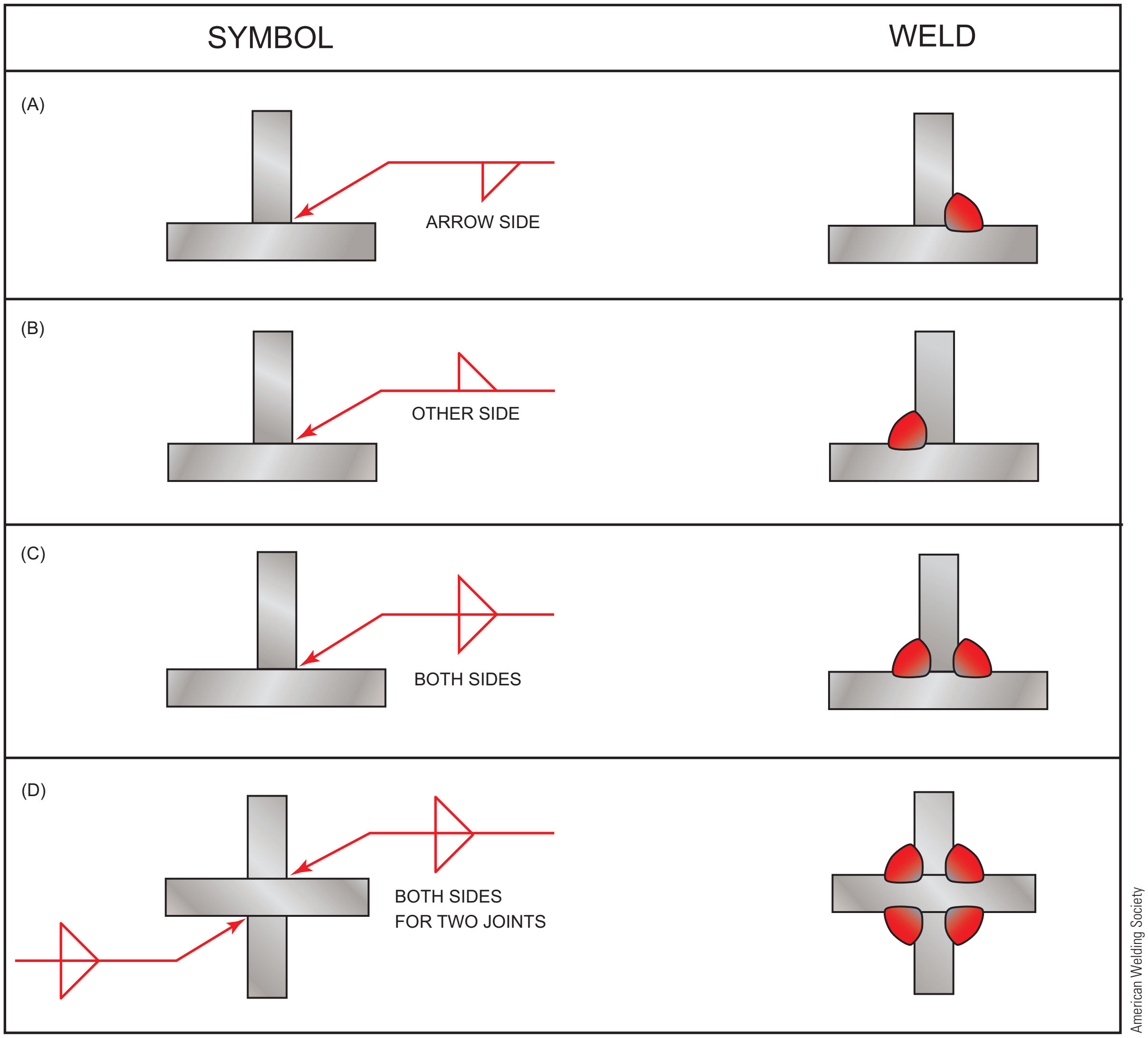

FIGURE 22-18 Designating weld locations.

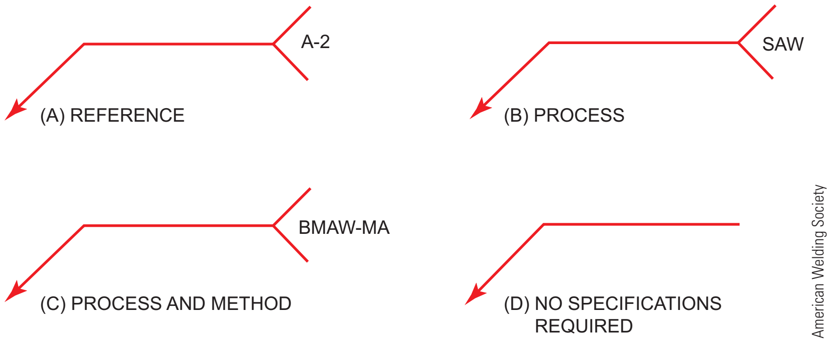

FIGURE 22-19 Locations of specifications, processes, and other references on weld symbols.

On a drawing, when a joint is illustrated by a single line and the arrow of a welding symbol is directed to the line, the arrow side of the joint is considered to be the near side of the joint.

For welds designated by the plug, slot, spot, seam, resistance, flash, upset, or projection welding symbols, the arrow connects the welding symbol reference line to the outer surface of one of the members of the joint at the centerline of the desired weld. The member to which the arrow points is considered to be the arrow side member. The remaining member of the joint is considered to be the other side member.

Fillet Welds

Dimensions of fillet welds are shown on the same side of the reference line as the weld symbol and are shown to the left of the symbol, **Figure 22-20A**. When both sides of a joint have the same size fillet welds, they are dimensioned as shown in **Figure 22-20B**. When both sides of a joint have different size fillet welds, both are dimensioned, **Figure 22-20C**. When the dimensions of one or both welds differ from the dimensions given in the general notes, both welds are dimensioned. The size of a fillet weld with unequal legs is shown in parentheses to the left of the weld symbol, **Figure 22-20D**. The length of a fillet weld, when indicated on the welding symbol, is shown to the right of the weld symbol, **Figure 22-20E**. In intermittent fillet welds, the length and pitch increments are placed to the right of the weld symbol, **Figure 22-21**. The first number represents the length of the weld, and the second number represents the pitch or the distance between the centers of two welds.

Intermittent welds can be used to reduce the amount of welding and possible weld distortion and to prevent a crack from spreading. It is easier for a crack to propagate through a continuous weld than it is on an intermittent weld, where it has to restart at the beginning of each weld, **Figure 22-22**.

Plug Welds

Holes in the arrow side member of a joint for plug welding are indicated by placing the weld symbol below the reference line. Holes in the other side member of a joint for plug welding are indicated by placing the weld symbol above

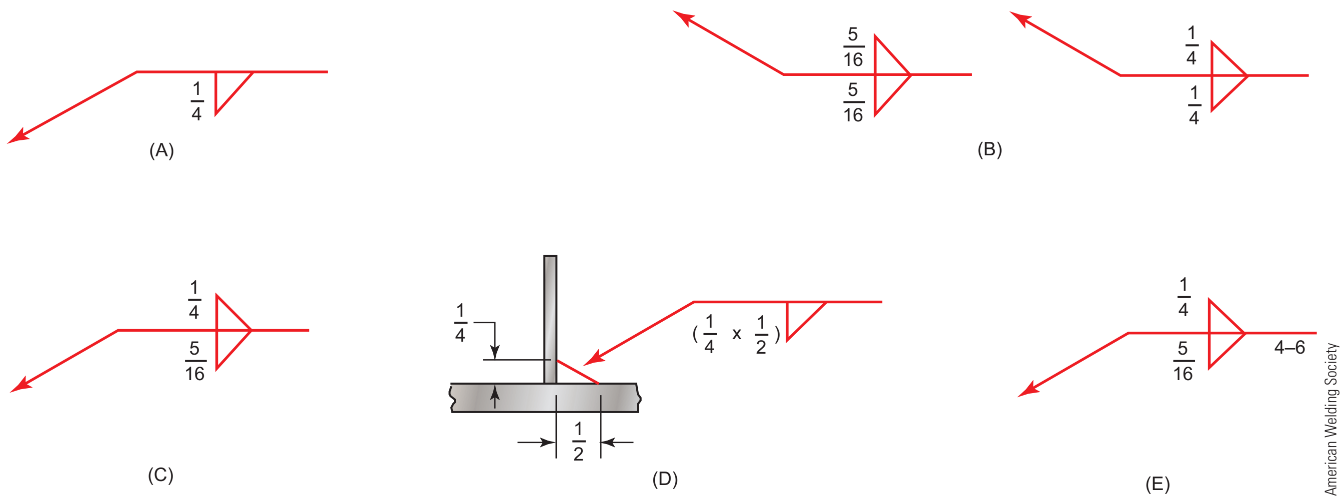

FIGURE 22-20 Dimensioning the fillet weld symbol.

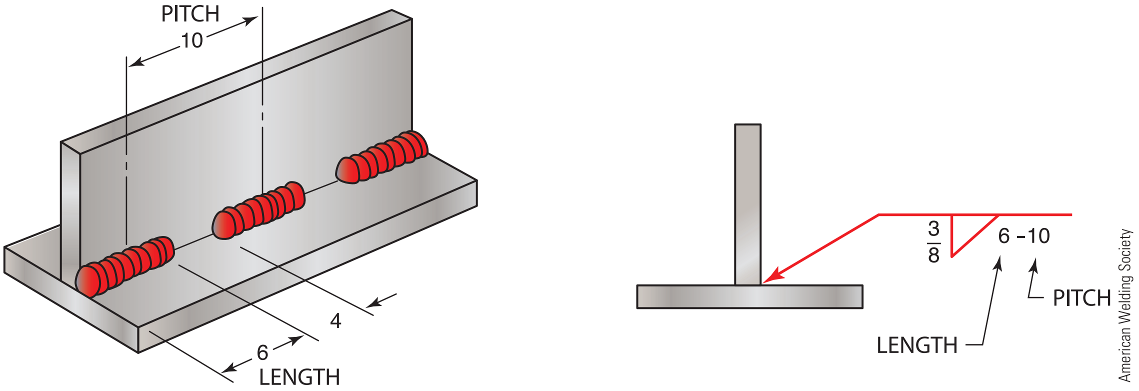

FIGURE 22-21 Dimensioning intermittent fillet welds.

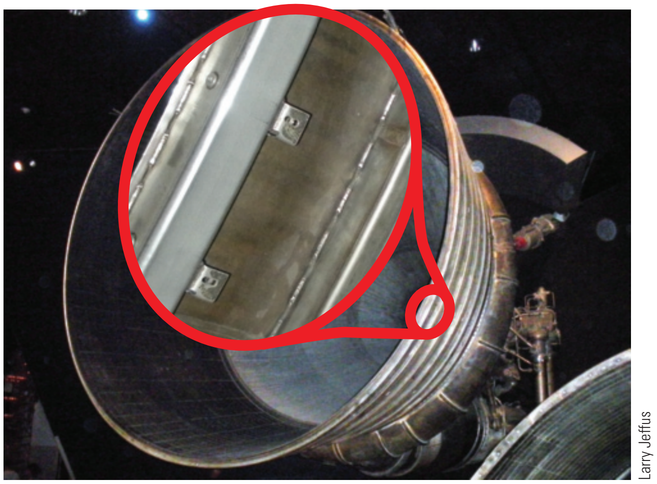

FIGURE 22-22 Intermittent welds were used to help prevent cracks from spreading due to the severe vibration and stress during the launching of the Saturn V booster rocket, which was used to launch astronauts to the moon.

the reference line, **Figure 22-23**. Refer to Figure 22-23 for the location of the dimensions used on plug welds. The diameter or size is located to the left of the symbol (A). The angle of the sides of the hole, if not square, is given above the symbol (B). The depth of buildup, if not completely flush with the surface, is given in the symbol (C). The center-to-center dimensioning or pitch is located on the right of the symbol (D).

Spot Welds

Dimensions of resistance spot welds are indicated on the same side of the reference line as the weld symbol, **Figure 22-24**. Such welds are dimensioned either by size or by strength. The size is designated as the diameter of the weld expressed in fractions or in decimal hundredths of an inch. The size is shown with or without inch marks to the left of the weld symbol. The center-to-center spacing (pitch) is shown to the right of the symbol.

The strength of spot welds is shown as the minimum shear strength in pounds (newtons) per spot and is shown to the left of the symbol, **Figure 22-25A**. When a definite number of spot welds are desired in a certain joint, the quantity is placed above or below the weld symbol in parentheses, **Figure 22-25B**.

Seam Welds

Dimensions of seam welds are shown on the same side of the reference line as the weld symbol. Dimensions relate to either size or strength. The size of seam welds is designated as the width of the weld expressed in fractions or decimal hundredths of an inch. The size is shown with or without the inch marks to the left of the weld symbol, **Figure 22-26A**. When the length of a seam weld is indicated on the symbol, it is shown to the right of the symbol, **Figure 22-26B**. When seam welding extends for the full distance between abrupt changes in the direction of welding, a length dimension is not required on the welding symbol.

The strength of seam welds is designated as the minimum acceptable shear strength in pounds per linear inch. The strength value is placed to the left of the weld symbol, **Figure 22-27**.

Groove Welds

Joint strengths can be improved by making some type of groove preparation before the joint is welded. There are seven types of grooves. The groove can be made in one or both plates or on one or both sides. By cutting the groove in the plate, the weld can penetrate deeper into the joint. This helps to increase the joint strength without restricting weldment flexibility.

The grooves can be cut in base metal in a number of different ways. The groove can be cut using an oxyfuel cutting torch, air carbon arc cutting, plasma arc cutting, machining, or saws.

The various types of groove welds are classified as follows:

- Single-groove and symmetrical double-groove welds that extend completely through the members being joined. No size is included on the weld symbol, **Figure 22-28A** and **B**.

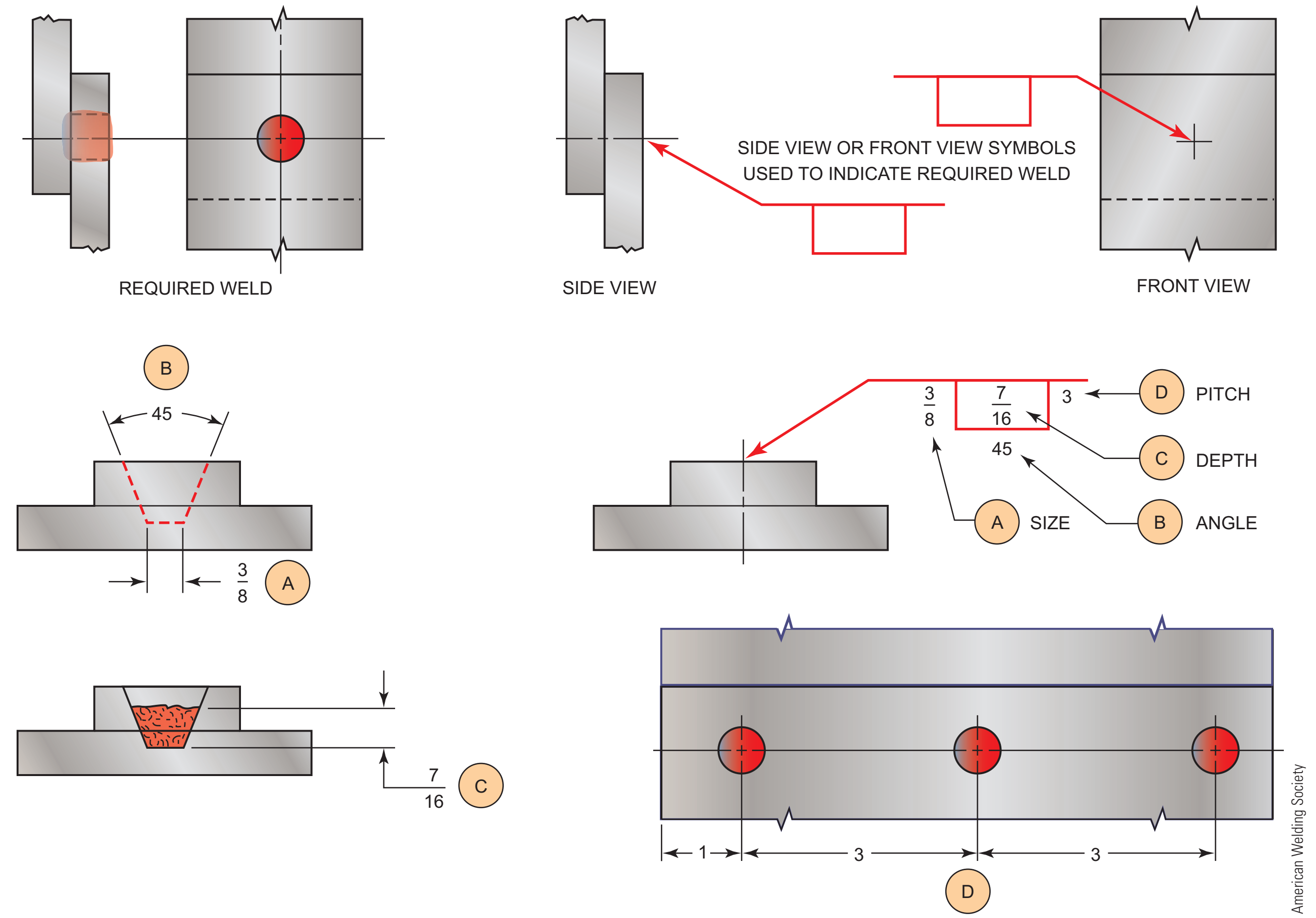

FIGURE 22-23 Applying dimensions to plug welds.

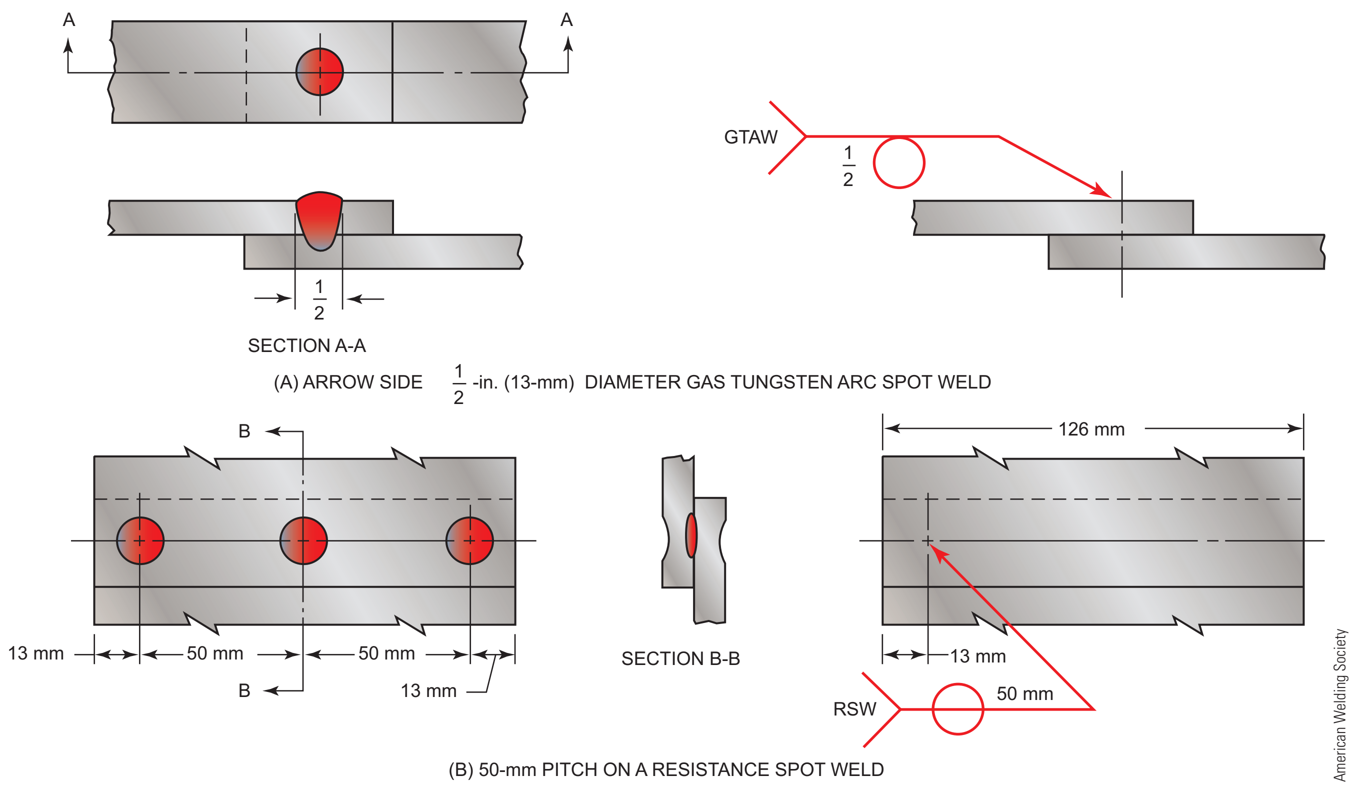

FIGURE 22-24 Spot welding symbols.

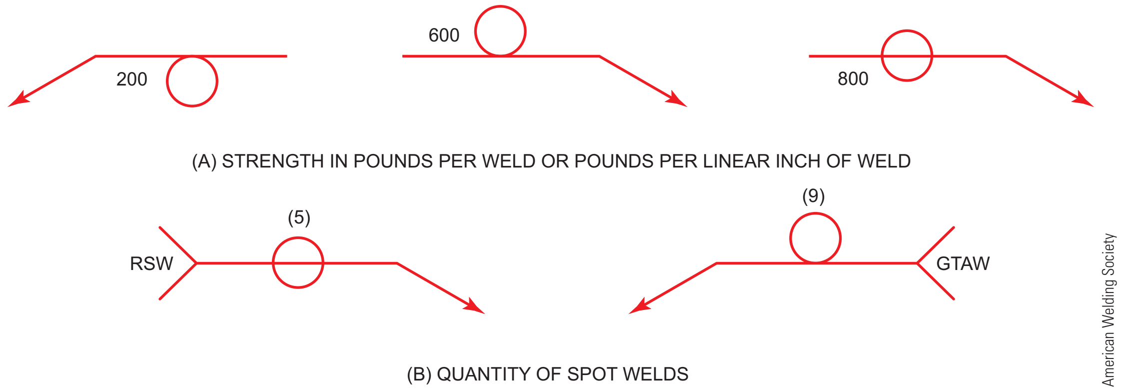

FIGURE 22-25 Designating strength and number of spot welds.

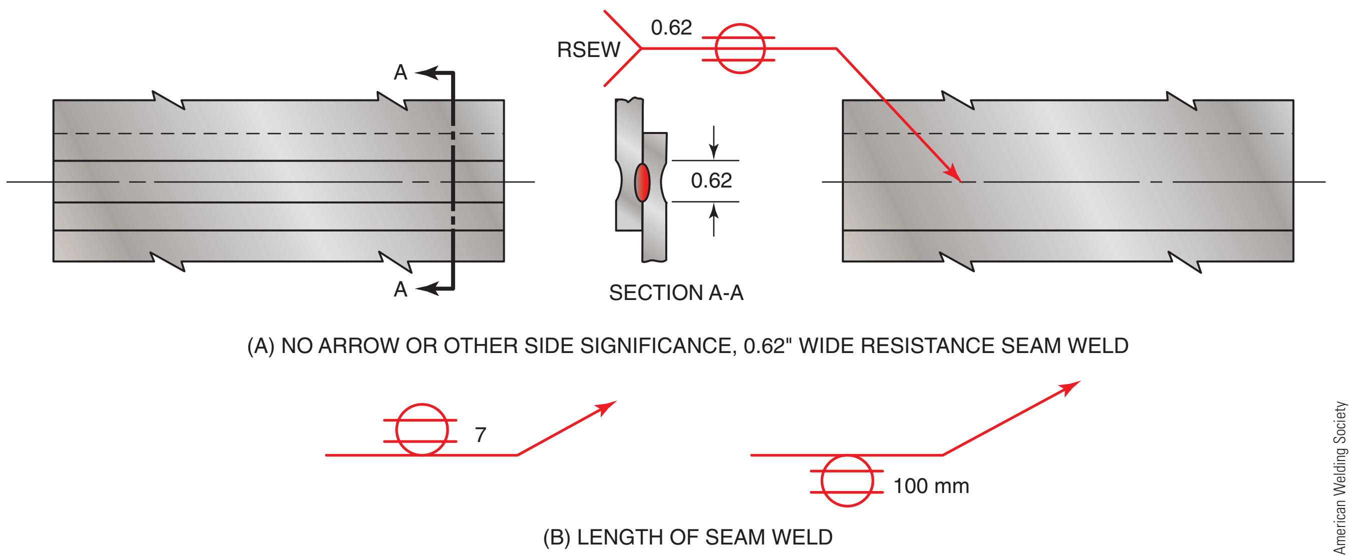

FIGURE 22-26 Designating the size of a seam weld.

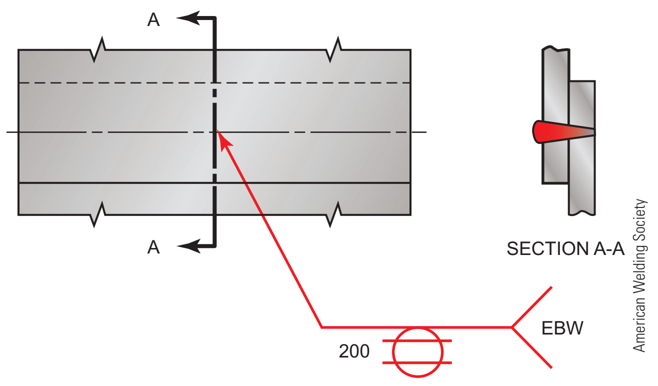

FIGURE 22-27 Strength of seam weld with an electron beam.

- Groove welds that extend only partway through the parts being joined. The size as measured from the top of the surface to the bottom (not including reinforcement) is included to the left of the welding symbol, **Figure 22-28C**.
- The size of groove welds with a specified *effective throat* is indicated by showing the depth of groove preparation with the effective throat appearing in parentheses and placed to the left of the weld symbol, **Figure 22-28D**. The size of square groove welds is indicated by showing the root penetration. The depth of chamfering and the root penetration are read in that order from left to right along the reference line.
- The root opening of groove welds is the user's standard unless otherwise indicated. The root opening of groove welds, when not the user's standard, is shown inside the weld symbol, **Figure 22-28E** and **F**.
- The root face's main purpose is to minimize the burn-through that can occur with a feather edge. The size of the root face is important to ensure good root fusion, **Figure 22-29**.
- The size of flare groove welds is considered to extend only to the tangent points of the members, **Figure 22-30**.

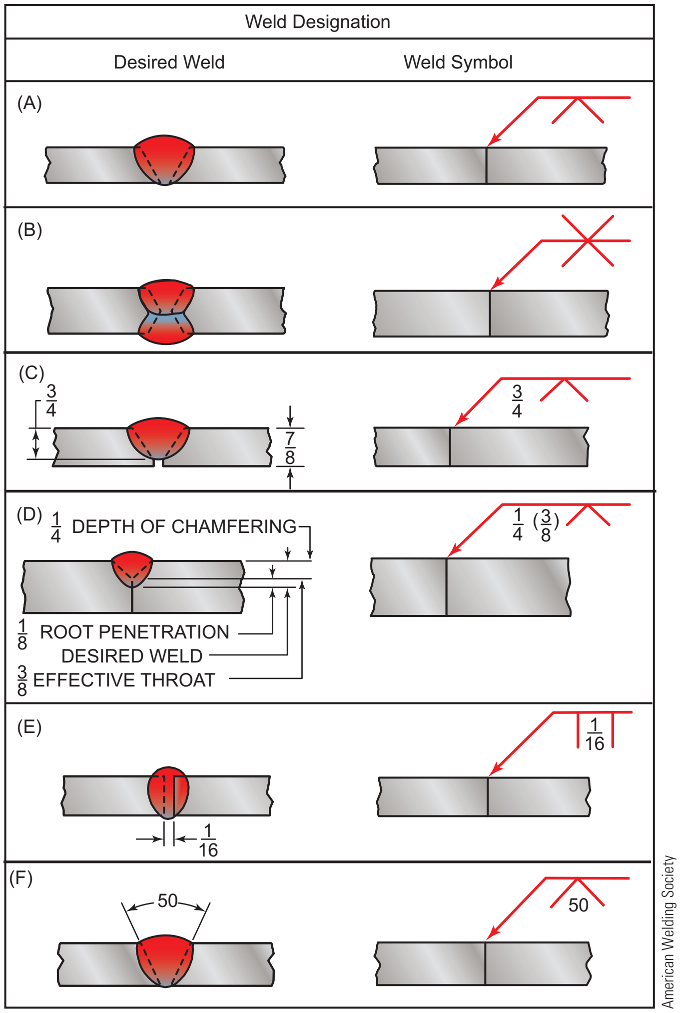

FIGURE 22-28 Designating groove weld location, size, and root penetration.

Backing

A backing (strip) is a piece of metal that is placed on the back side of a weld joint. The backing must be thick enough to withstand the heat of the root pass as it is burned in. A backing strip may be used on butt joints, tee joints, and outside corner joints, **Figure 22-31**.

The backing may be either left on the finished weld or removed following welding. If the backing is to be

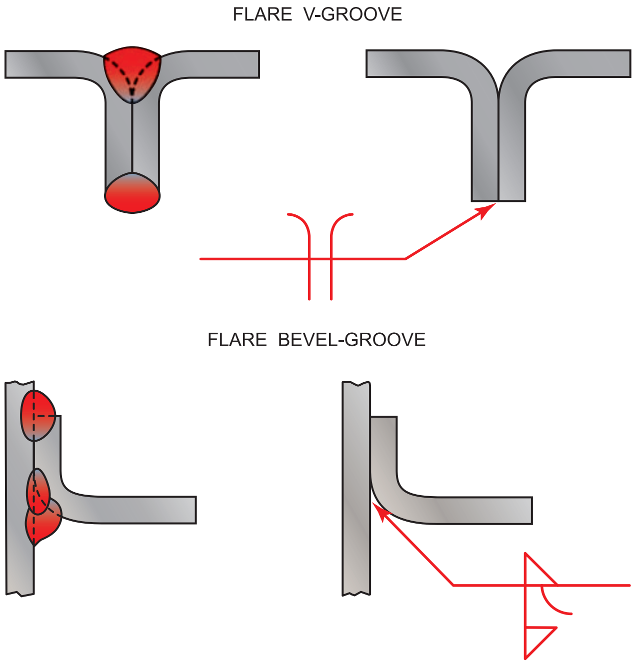

FIGURE 22-30 Designating flare V-groove and flare bevel groove welds.

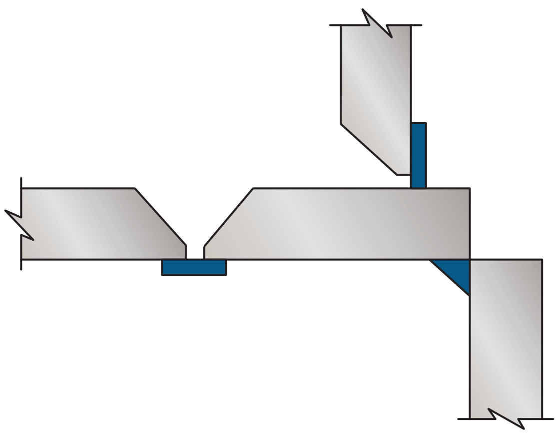

FIGURE 22-31 Backing strips.

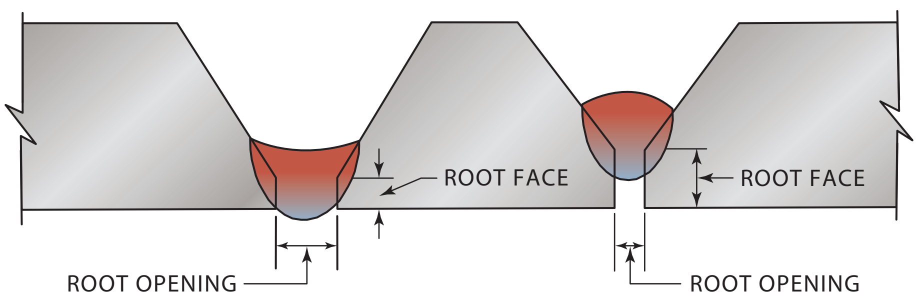

FIGURE 22-29 Effect root dimensioning can have on groove weld penetration.

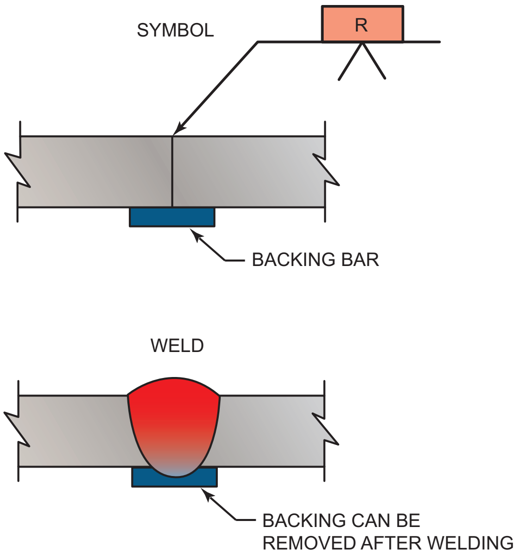

FIGURE 22-32 Butt weld with backing plate.

removed, then the letter *R* is placed in the backing symbol, **Figure 22-32.** The backing is often removed for a finished weld because it can be a source of stress concentration and a crevice that promotes rusting.

Flanged Welds

The following welding symbols are used for light-gauge metal joints where the edges to be joined are bent to form flange or flare welds.

- Edge flange welds are shown by the edge flange weld symbol.
- Corner flange welds are indicated by the corner flange weld symbol.
- Dimensions of flange welds are shown on the same side of the reference line as the welding symbol. They are placed on the left side of the symbol, **Figure 22-33**. The radius and height above the point of tangency are indicated by showing both the radius and the height separated by a plus sign.
- The size of the flange weld is shown by a dimension placed outward from the flanged dimensions.

Nondestructive Testing Symbols

The increased use of nondestructive testing (NDT) as a means of quality assurance has resulted in the development of standardized symbols. They are used by the designer or engineer to indicate the area to be tested and the type of test to be used. The inspection symbol uses the same basic reference line and arrow as the welding symbol, **Figure 22-34**.

The symbol for the type of nondestructive test to be used, **Table 22-1**, is shown with a reference line. The location above, below, or on the line has the same significance as it does with a welding symbol. Symbols above the line indicate other side, symbols below the line indicate arrow side, and symbols on the line indicate no preference for the side to be tested, **Figure 22-35**. Some tests may be performed on both sides; therefore, the symbol appears on both sides of the reference line.

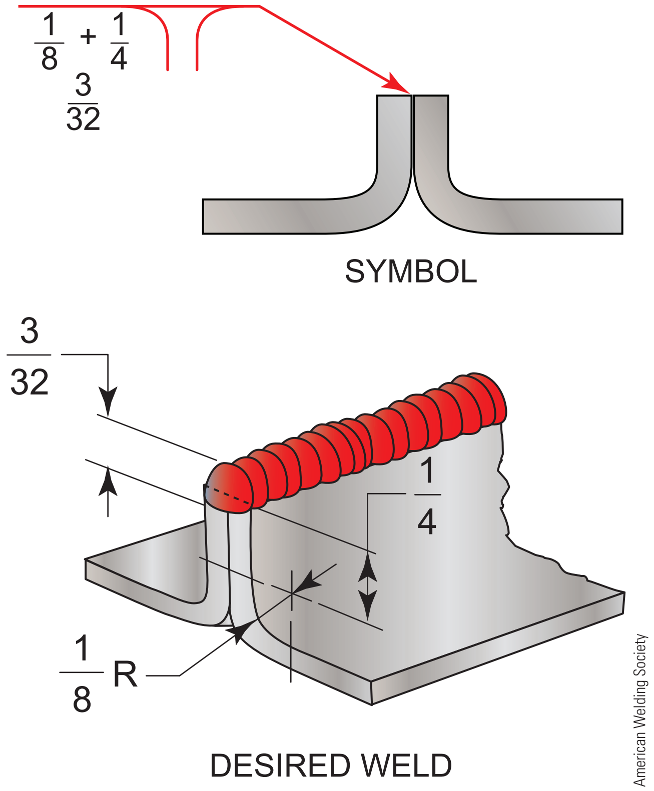

FIGURE 22-33 Applying dimensions to flange welds.

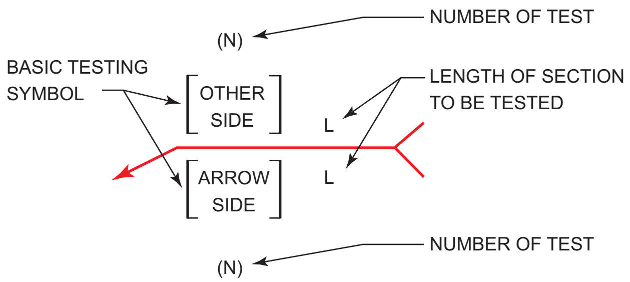

FIGURE 22-34 Basic nondestructive testing symbol.

Type of Nondestructive Test	Symbol
Visual	VT
Penetrant	PT
Dye penetrant	DPT
Fluorescent penetrant	FPT
Magnetic particle	MT
Eddy current	ET
Ultrasonic	UT
Acoustic emission	AET
Leak	LT
Proof	PRT
Radiographic	RT
Neutron radiographic	NRT

TABLE 22-1 Standard Nondestructive Testing Symbols

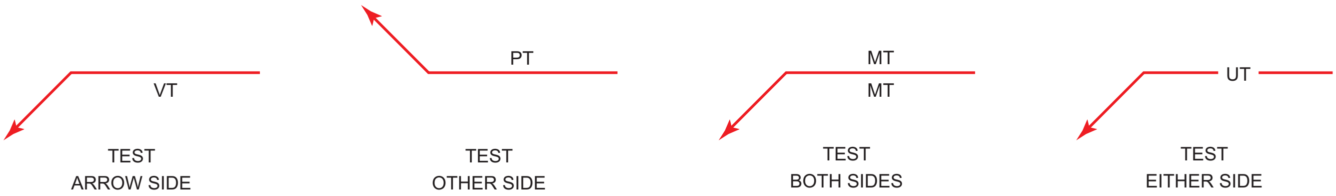

FIGURE 22-35 Testing symbols used to indicate what side is to be tested.

Two or more tests may be required for the same section of weld. **Figure 22-36** shows methods of combining testing symbols to indicate more than one type of test to be performed.

The length of weld to be tested or the number of tests to be made can be noted on the symbol. The length either may be given to the right of the test symbol, usually in inches, or can be shown by the arrow line, **Figure 22-37**. The number of tests to be made is given in parentheses ( ) above or below the test symbol, **Figure 22-38**. The welding symbols and nondestructive testing symbols can be combined into one symbol, **Figure 22-39**. The **combination symbol** may help both the welder and inspector to identify welds that need special attention. A special symbol can be used to show the direction of radiation used in a radiographic test, **Figure 22-40**.

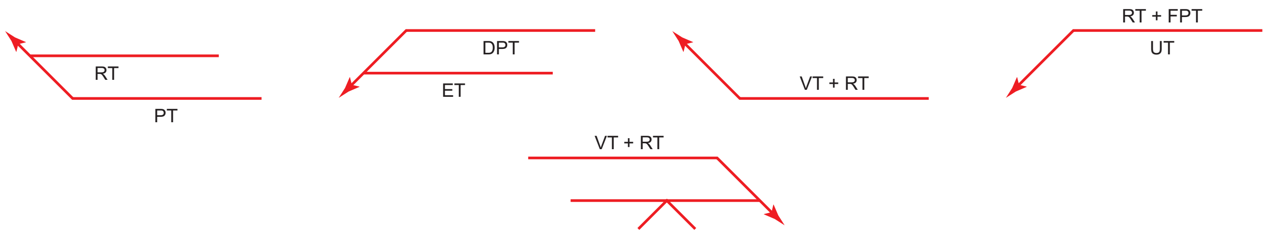

FIGURE 22-36 Methods of combining testing symbols.

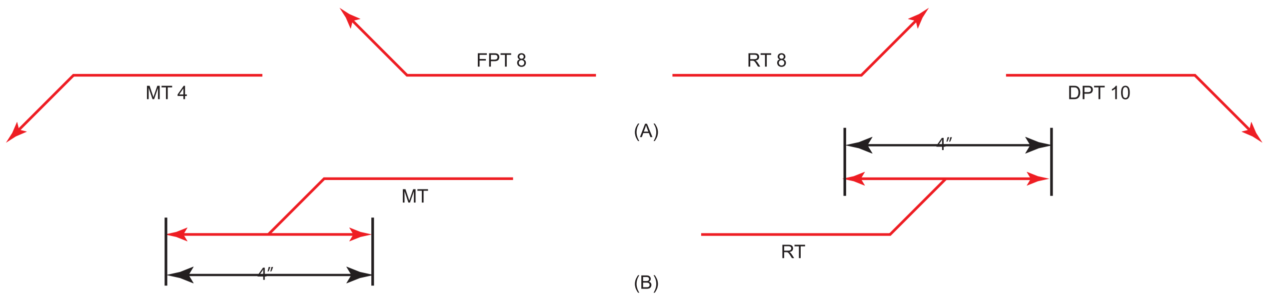

FIGURE 22-37 Two methods of designating the length of weld to be tested.

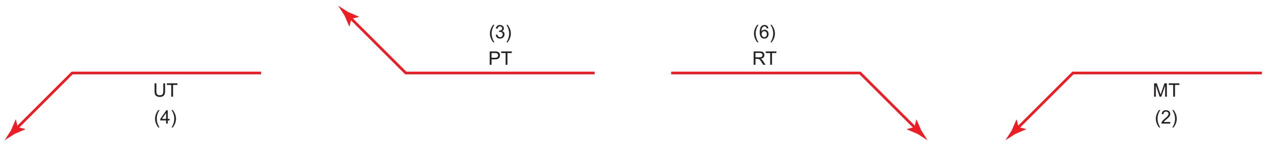

FIGURE 22-38 Method of specifying the number of tests to be made.

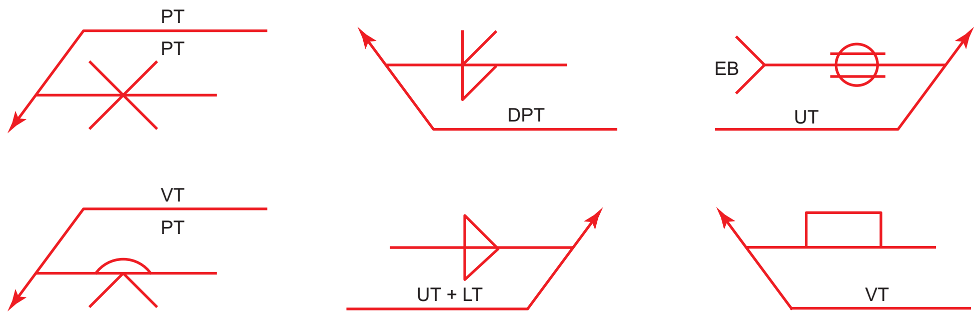

FIGURE 22-39 Combination weld and nondestructive testing symbols.

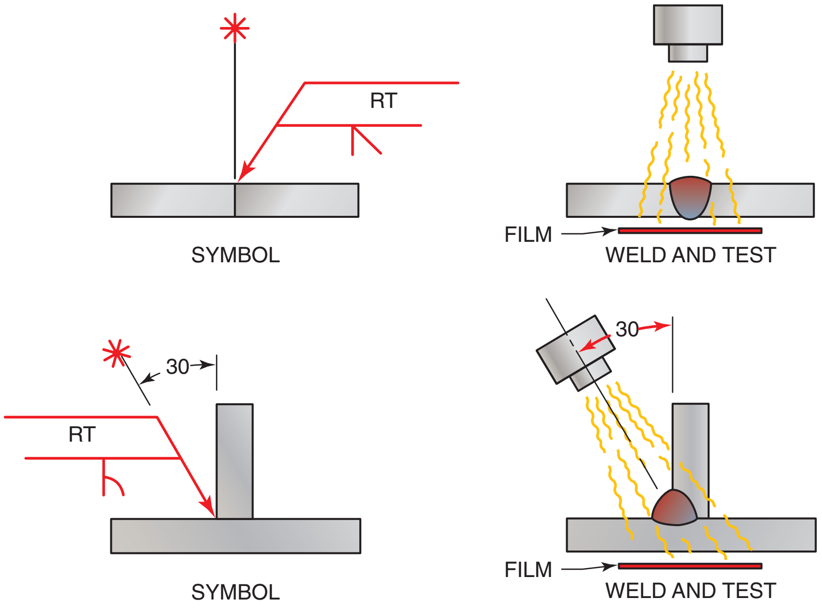

FIGURE 22-40 Combination symbol for weld and radiation source location for testing.

PRACTICE 22-1

Reading Welding Symbols

Using a pencil and lined paper, you are going to identify the welding symbols identified by the red numbered circles shown in **Figure 22-41**. Write the numbers 1 through 9 vertically down the left side of the page. Next to each number, sketch a cross-section of the weld indicated by the welding symbol. Next, write a statement explaining each of the parts of the welding symbol. ◆

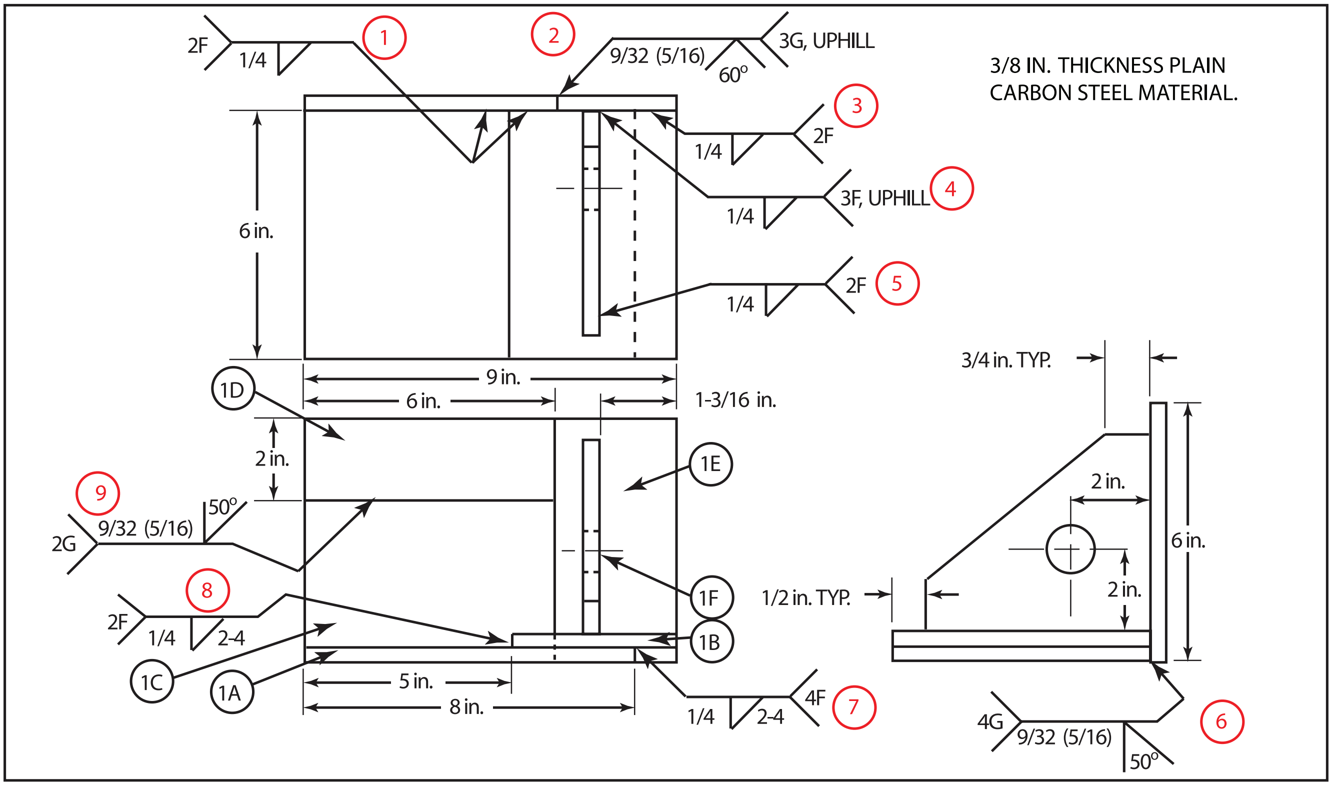

FIGURE 22-41 Weld symbols identification.

Summary

Understanding the physics of joint design is essential for the welder so that you can recognize and anticipate the various forces that will be applied to a weldment in the field. In this way, you can select the proper weld joint configuration to withstand these forces. Engineers use static and dynamic loading computer programs to anticipate the weldment's strength requirements. However, from time to time a welder will be asked to make changes in structures as part of a modification or repair. In the field, the welder is expected to understand the types of forces being applied to the weldment and to determine the best joint design to prevent these forces from causing a structural failure.

You must also be able to interpret the meaning of welding symbols. Understanding the significance of a welding symbol will prevent one of the most common problems in the field—that of overwelding. A weld that is made excessively large can cause a structural failure as easily as one that is undersized. Welded structures must often flex under load. Weldments must be flexible within limits so they can give, so they are not brittle, and so they will not break. Overwelding can cause a structure to be too rigid and subject to a brittle fracture. *Do not overweld*.

Review

1. List the five joint types used in welding.
2. What stresses must a welded joint withstand?
3. Sketch and label five edge preparations used for welding joints.
4. Sketch a V-grooved butt joint, and label all of the joint's dimensions.
5. Sketch a weld on plates in the 1G and 1F positions.
6. Sketch a weld on plates in the 2G and 2F positions.
7. Sketch a weld on plates in the 3G and 3F positions.
8. Sketch a weld on plates in the 4G and 4F positions.
9. Sketch a weld on a pipe in the 1G position.
10. Sketch a weld on a pipe in the 5G position.
11. Sketch a weld on a pipe in the 2G position.
12. Sketch a weld on a pipe in the 6G position.
13. Sketch a weld on a pipe in the 6GR position.
14. Why are some joints back gouged?
15. Why is it usually better to make a weld in the flat position?
16. What is a prequalified joint?
17. Why is cost a consideration in joint design?
18. Why are welding symbols used?
19. What types of information can be included on a welding symbol?
20. Why is a tail added to the basic welding symbol?
21. What types of information may appear on the reference line of a welding symbol?
22. What are the different classifications of welds that a symbol can indicate?
23. How is the reference line always drawn?
24. What is meant if the weld symbol is placed below the reference line?
25. How are the dimensions for a fillet weld given?
26. What dimensions can be given for a plug weld?
27. What two units are used to show the minimum shear strength of a spot weld?
28. How is the strength of a seam weld specified?
29. How can the groove be cut on the edge of a plate?
30. Sketch and dimension a V-groove weld symbol for a weld on the arrow side, with 1/8-in. root opening, 3/4 in. in size, and with a groove angle of 45°.
31. How is the removal of the backing strip noted on a welding symbol?
32. How are flanged edges formed?
33. Sketch two NDT symbols illustrating different methods that can be used to indicate multiple test requirements for the same section of weld.

Chapter 23

Fabricating Techniques and Practices

OBJECTIVES

After completing this chapter, the student should be able to

- explain the various safety issues related to fabrication.
- list the advantages of using custom fabrication parts.
- demonstrate an understanding of the proper placement of tack welds.
- demonstrate the use of location and alignment points when assembling a project.
- explain how to adjust parts to meet the tolerance.
- describe how to control weld distortion.
- lay out and trace parts.
- identify common sizes and shapes of metals used in weldments.
- describe how to assemble and fit up parts for welding.

KEY TERMS

assembly
contour marker
custom fabrication
fabrication
fitting
fixtures
kerf
nesting
tack welds
tolerance
weldment

INTRODUCTION

The first step in almost every welding operation is the **assembly** of the parts to be joined by welding. At the very basic level, assembly can be just placing two pieces of metal flat on a table and tack welding them together for practice welding. At a higher level is the assembly of complex equipment, buildings, ships, or other large welded structures. The important thing to remember, however, is that no matter how large or complicated the welded structure, it is assembled one piece at a time. That is true for a simple project you build as part of your welding shop learning in school or for the ship, rocket engine, or building you might construct one day.

FABRICATION

In addition to straight welding, welders are often required to fabricate a weldment. **Fabrication** is the process of assembling the parts to form a weldment. It can include layout, measuring, cutting, grinding, fitting, tack welding, and so on. The term **weldment** is a general term that refers to anything that was created primarily by welding. It may form a completed project or may only be part of a larger structure. Some weldments are composed of two or three parts; others may have hundreds or even thousands of individual parts, **Figure 23-1**. Even the largest weldments start by placing two parts together.

The number and type of steps required to take a plan and create a completed project vary depending on the complexity and size of the finished weldment. All welding projects start with a plan. This plan can range from a simple one that exists only in the mind of the welder to a very complex plan comprising a set of drawings. As a beginning welder, you must learn how to follow a set of drawings to produce a finished weldment.

Soon we will be fabricating large structures in space, **Figure 23-2** and **Figure 23-3**. The International Space Station is being assembled in space from large sections built here on Earth. Most of these assemblies required some type of welding. Someday we expect to be welding in space. Research for welding in space dates back to the 1960s, with experiments done on board the US Skylab. Today, that research continues with experiments on the International Space Station.


Larry Jeffus

FIGURE 23-1 Petrol chemical refinery near Point Comfort, Texas along the southern Texas coast.

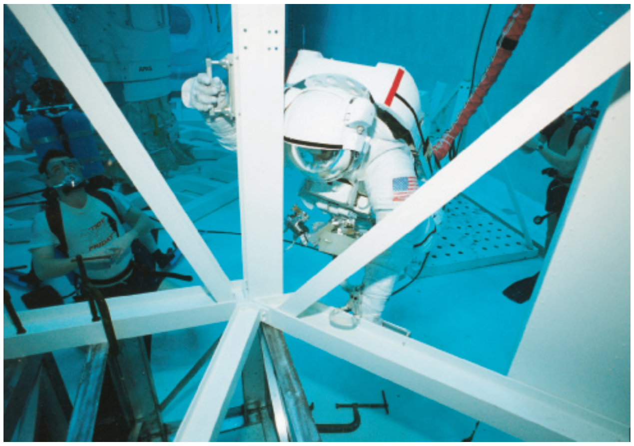
NASA

FIGURE 23-2 The neutral buoyancy tank allows divers to work in spacesuits to simulate the micro-gravity of space.


NASA

FIGURE 23-3 The International Space Station was assembled in space.

SAFETY

As with any welding, safety is of primary concern for fabrication of weldments. Fabrication may present some potential safety problems not normally encountered in straight shop welding. Unlike most practice welding, much of the larger fabrication work may need to be performed outside an enclosed welding booth. Additionally, several welders may be working on a structure at the same time. When you are welding around other workers who are not welders, you must let them know that you are going to be welding so they can protect themselves from the arc light, sparks, and other possible hazards. Tell them about the hazards because you cannot assume that they know about the hazards of welding. Extra care must be taken to ensure that burns do not occur on you or the other welders from the arc or hot sparks. When possible, you should erect portable welding curtains, **Figure 23-4**.

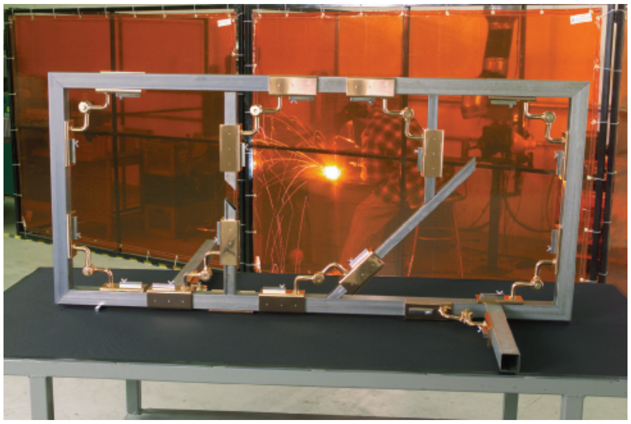
PIPCO

FIGURE 23-4 Portable welding curtains help protect other workers from arc flash.

Ventilation is also important because the normal shop ventilation may not extend to the fabrication area. A portable fan may be needed to help blow the welding fumes away from the work area. Be sure the fan blows the fumes away from you and others.

Often you will be working in an area that has welding cables, torch hoses, extension cords, and other trip hazards lying around on the floor. These must be flat on the floor and should be covered if they are in a walkway to prevent accidental tripping. Keep all of the scrap metal and other debris picked up; a neat work area is a safe work area.

As the fabrication grows in size, it will become heavier. Make sure that it is stable and not likely to fall. A weldment that starts out stable and well supported can become unstable and likely to fall as it grows in size. Keeping it well supported is important, especially if you have to crawl under it to weld on the bottom side. Check with your supervisor or shop safety officer before working under any weldment.

These and other safety concerns are covered in Chapter 2, "Welding Safety." You should also read any safety booklets supplied with the equipment before starting any project.

PARTS AND PIECES

Welded fabrications can be made from precut and preformed parts, or they can be made from hand-cut and hand-formed parts, **Figure 23-5A**, **B**, and **C**. In most cases, weldments are made using a variety of precut and preformed parts along with handmade pieces.

Preformed

Preshaped pieces may be precut, bent, machined, or otherwise prepared before you receive them. This is a common practice in large shops and on large-run projects. Large shops may have an entire department dedicated to material and part preparation. When a large number of the same items are made in a large-run shop, it may outsource some of the parts to shops that specialize in mass-producing items. When making an assembly with precut and preformed parts, little or no on-the-job fitting may be required. That, of course, depends on how accurately the parts were prepared.

Larry Jeffus

FIGURE 23-5 (A) Magnetic pipe wrap helps guide the plasma arc cutting torch.

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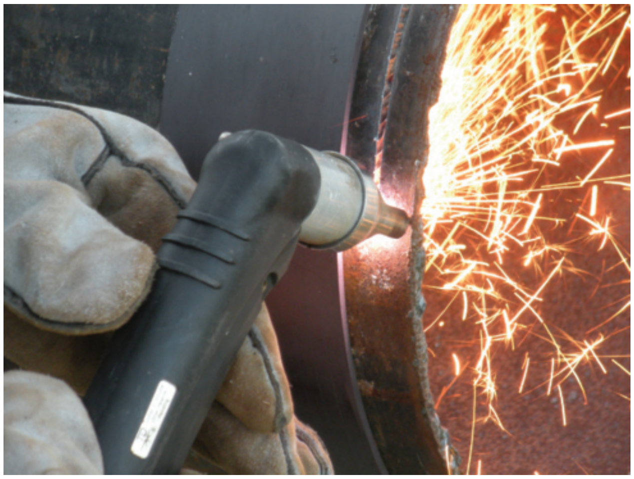
FIGURE 23-5 (B) Supporting yourself and your arms makes it easier to make smooth cuts.



Larry Jeffus

FIGURE 23-5 (C) The guide helps you make the cut straight.

Custom Fabrication

The opposite end of the spectrum from preformed parts is **custom fabrication** in which all or most of the assembly is handmade, **Figure 23-6**. This might include cutting,

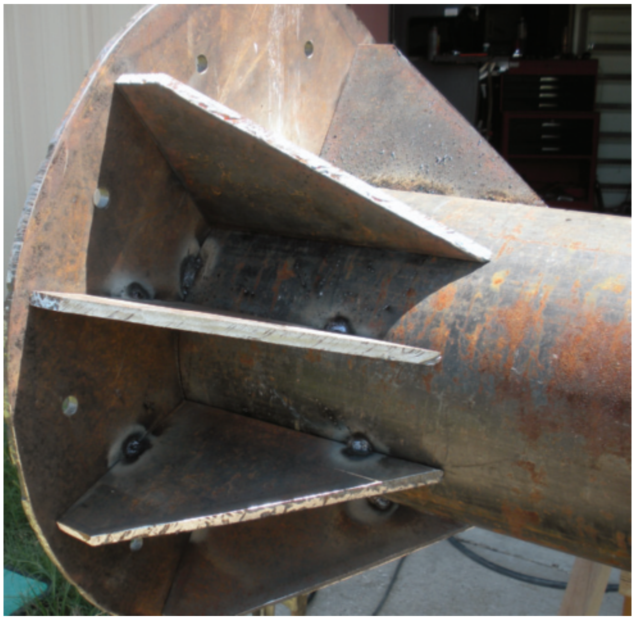


FIGURE 23-6 Custom tower base for a wind energy generator.

bending, grinding, drilling, or other similar processes, **Figure 23-7**. Almost all weldments were produced by hand until the introduction of automated equipment for cutting, bending, and machining. Today, many items, including some large machines and almost all repair work, are still custom fabricated.

Using preformed parts has a number of advantages:

- Cost—Shops that specialize in cutting out mass numbers of similar parts can do it less expensively than for the same parts that can be made one by one by hand.
- Speed—High-speed cutting and forming machines can produce a large number of items quickly.
- Accuracy—Automated equipment can make parts that are more accurate than hand-made parts.
- Less waste—The wise use of materials is important to both control cost and to conserve natural resources.

Custom fabricating parts has a number of advantages:

- Originals—It is not practical to set up an automated process when there will be only a one-of-a-kind item or a limited number of an item produced.
- Prototypes—Often, even if there are going to be thousands or even tens of thousands of a weldment produced, the first one, the prototype, must be made by hand to be sure that everything works as it was planned.
- Repairs—Seldom would it be necessary to make a large number of the same part or piece when making a repair on a damaged or worn item.
- Custom jobs—Sometimes people want to have something special or unique built or modified just for them.

FIGURE 23-7 Magnetic drill makes it easier to drill holes accurately.

LAYOUT

Parts for fabrication may require that the welder lay out lines and locate points for cutting, bending, drilling, and assembling. Lines may be marked with a soapstone or a chalk line, scratched with a metal scribe, or punched with a center punch, **Figure 23-8**. If a piece of soapstone is used, it should be sharpened properly to increase accuracy, **Figure 23-9**. A chalk line will make a long, straight line on metal and is best used on large jobs, **Figure 23-10**. Both the scribe and punch can be used to lay out an accurate line, but the punched line is easier to see when cutting. A punch can be held as shown in **Figure 23-11**, with the tip just above the surface of the metal. When the punch is struck with a lightweight hammer, it will make a mark. If you move your hand along the line and rapidly strike the punch, it will leave a series of punch marks for the cut to follow.

Always start a layout as close to a corner of the material as possible. By starting in a corner or along the edge, you can take advantage of the preexisting cut as well as reduce wasted material.

Line Identification It is easy to cut the wrong line. In welding shops, one person may lay out the parts and another may make the cuts. Even when one person does both

FIGURE 23-8 (A) Paint marker, (B) grease marker, (C) felt tip marker, and (D) soapstone.

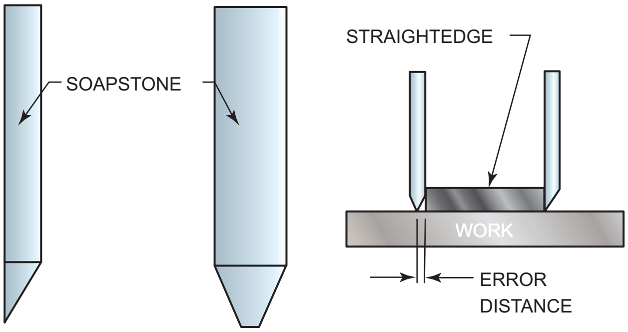


FIGURE 23-9 Proper method of sharpening a soapstone.

FIGURE 23-10 (A) Pull the chalk line tight and then snap the line.

FIGURE 23-10 (B) Check to see that the line is dark enough to be easily seen.

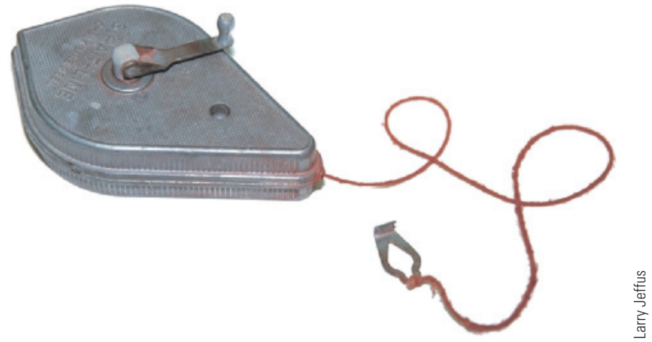


FIGURE 23-10 (C) Chalk line reel; powdered chalks are available in several different colors.

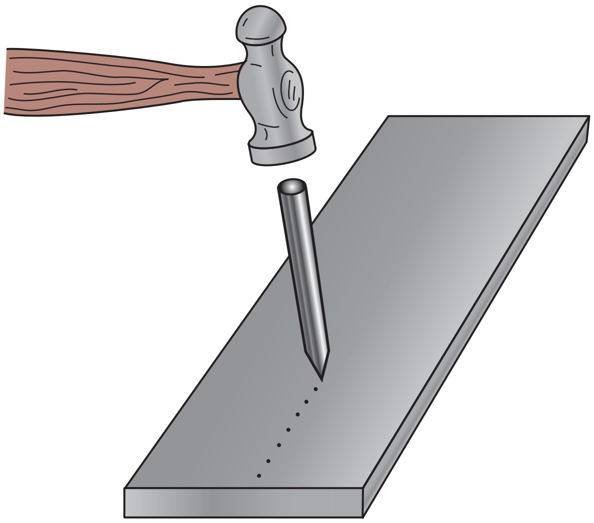


FIGURE 23-11 Holding the punch slightly above the surface allows it to be struck repeatedly, making punched marks to form a punched line that is easily seen for cutting.

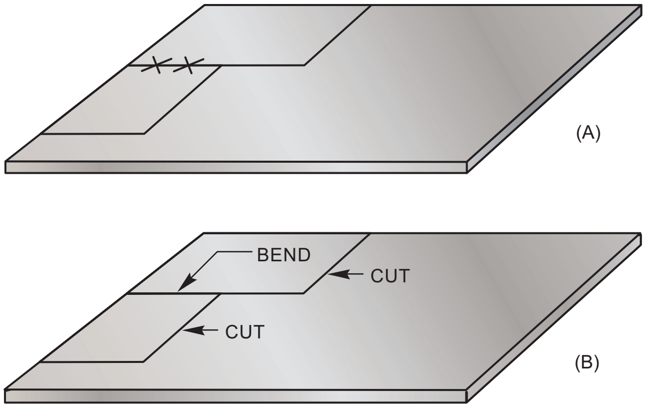


FIGURE 23-12 Identifying layout lines helps prevent mistakes during cutting.

Larry Jeffus

FIGURE 23-13 Marking parts makes it less likely that the wrong one is welded in place.

jobs, it is easy to cut the wrong line, either because of the restricted view through cutting goggles or because of the large number of lines on a part. To avoid making a cutting mistake, always identify whether lines are being used for cutting, for locating bends, as drill centers, or as assembly locations. The lines not to be cut may be marked with an *X*, **Figure 23-12A**, or they may be identified by writing directly on the part, **Figure 23-12B**. Mark the side of the line that is scrap so that when the kerf is removed from that side, the part will be the proper size. Any lines that have been used for constructing the actual layout line or to locate points for drilling or are made in error must be erased completely or clearly marked to avoid confusion during cutting and assembly.

Some shops have their own shorthand methods for identifying layout lines, or you can develop your own system. Failure to develop and use a system for identifying lines will ultimately result in a mistake, **Figure 23-13**. In a welding shop you will find only those who have made the wrong cut and those who will make the wrong cut. When it does happen, check with the welding shop supervisor to see what corrective steps can be taken. One advantage for most welding assemblies is that many cutting errors can be repaired by welding. Prequalified procedures are often established for just such an event, so check before deciding to scrap the part.

The process of laying out a part may be affected by the following factors:

- *Material shape:* **Figure 23-14** lists the most common metal shapes used for fabrication. Flat stock such as sheets and plates are easiest to lay out, and pipes and round tubing are the most difficult shapes to work with.
- *Part shape:* Parts with square and straight cuts are easier to lay out than parts with angles, circles, curves, and irregular shapes.
- *Tolerance:* The smaller or tighter the tolerance that must be maintained, the more difficult the layout.
- *Nesting:* The placement of parts together in a manner that will minimize the waste created is called **nesting**.

Parts with square or straight edges are the easiest to lay out. Simply measure the distance and use a square or straightedge to lay out the line to be cut, **Figure 23-15**. Straight cuts that are to be made parallel to an edge can be drawn by using a combination square and a piece of soapstone or scriber. Set the combination square to the correct dimension and drag it along the edge of the plate while holding the soapstone or scriber at the end of the combination square's blade, **Figure 23-16**.

PRACTICE 23-1

Laying Out Square, Rectangular, and Triangular Parts

Using a piece of metal or paper, soapstone or pencil, tape measure, and square, you will lay out the parts shown in **Figure 23-17**. The parts must be laid out within ± 1/16 in. of the dimensions. Convert the dimensions into SI metric units of measure.

Circles, arcs, and curves can be laid out by using either a compass or a circle template, **Figure 23-18**. The diameter is usually given for a hole or round part, and the radius is usually given for arcs and curves, **Figure 23-19**. The center of the circle, arc, or curve may be located using dimension lines and centerlines. Curves and arcs that are to be made tangent to another line may be dimensioned with only their radiuses, Figure 23-19.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

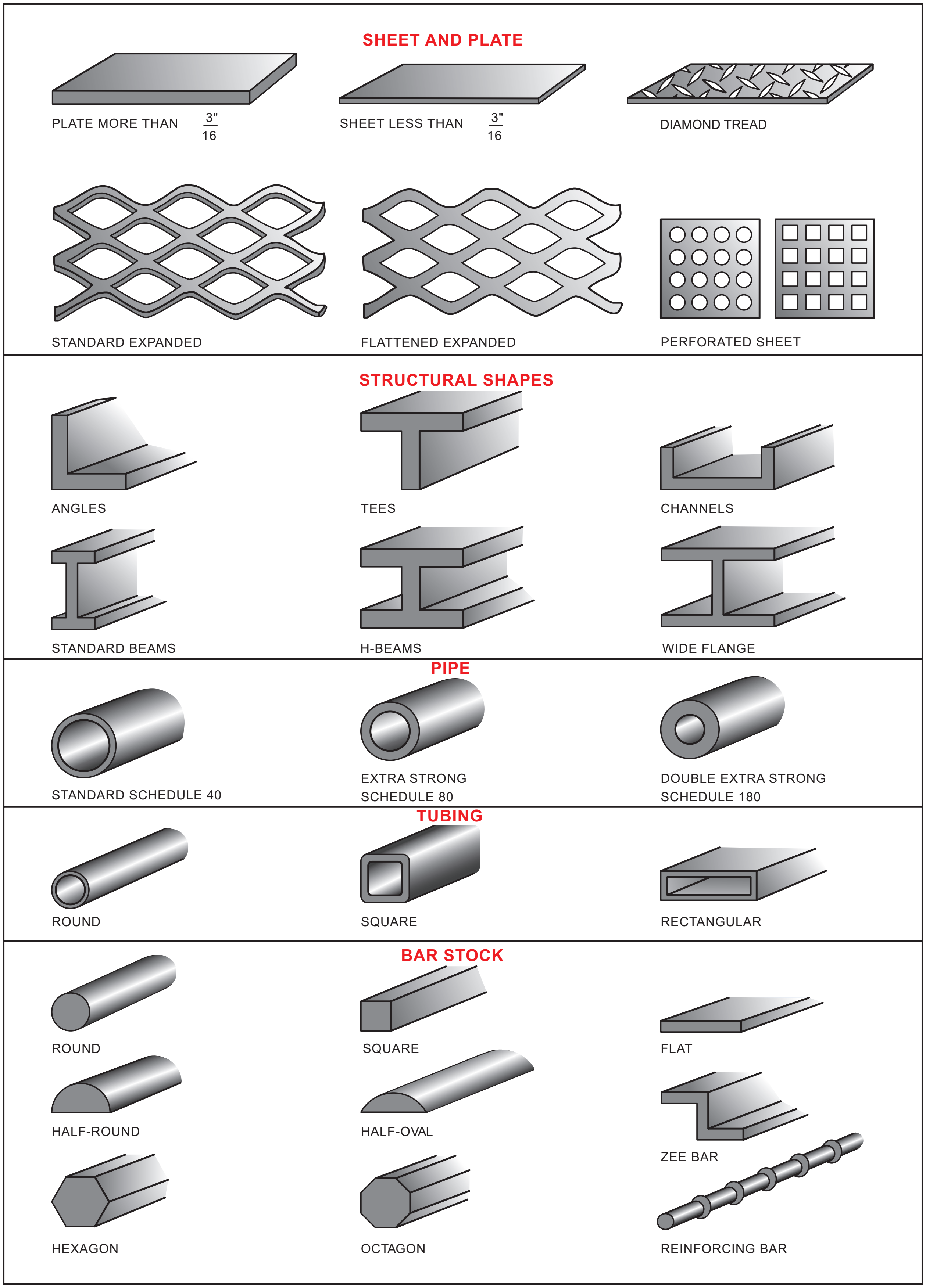


FIGURE 23-14 Standard metal shapes; most are available with different surface finishes, such as hot-rolled, cold-rolled, or galvanized.

FIGURE 23-15 Using a square to draw a straight line.

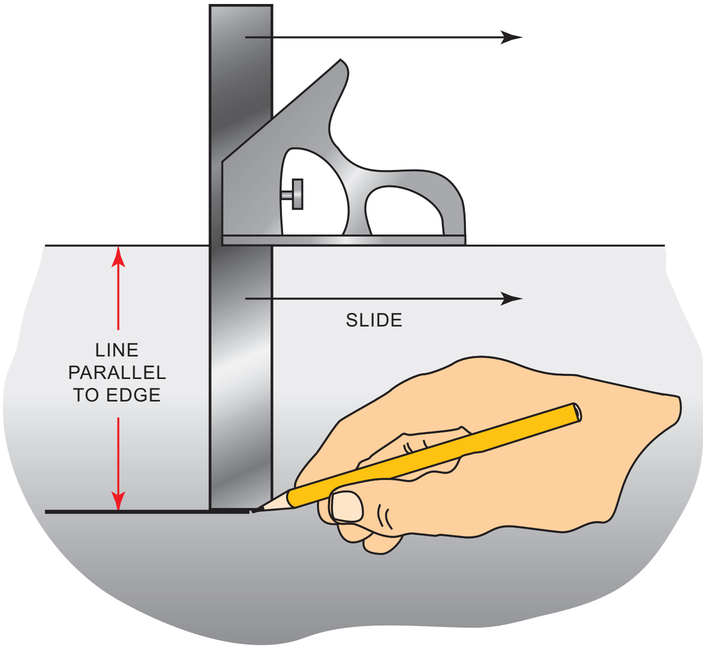


FIGURE 23-16 Using a combination square to lay out a strip of metal.

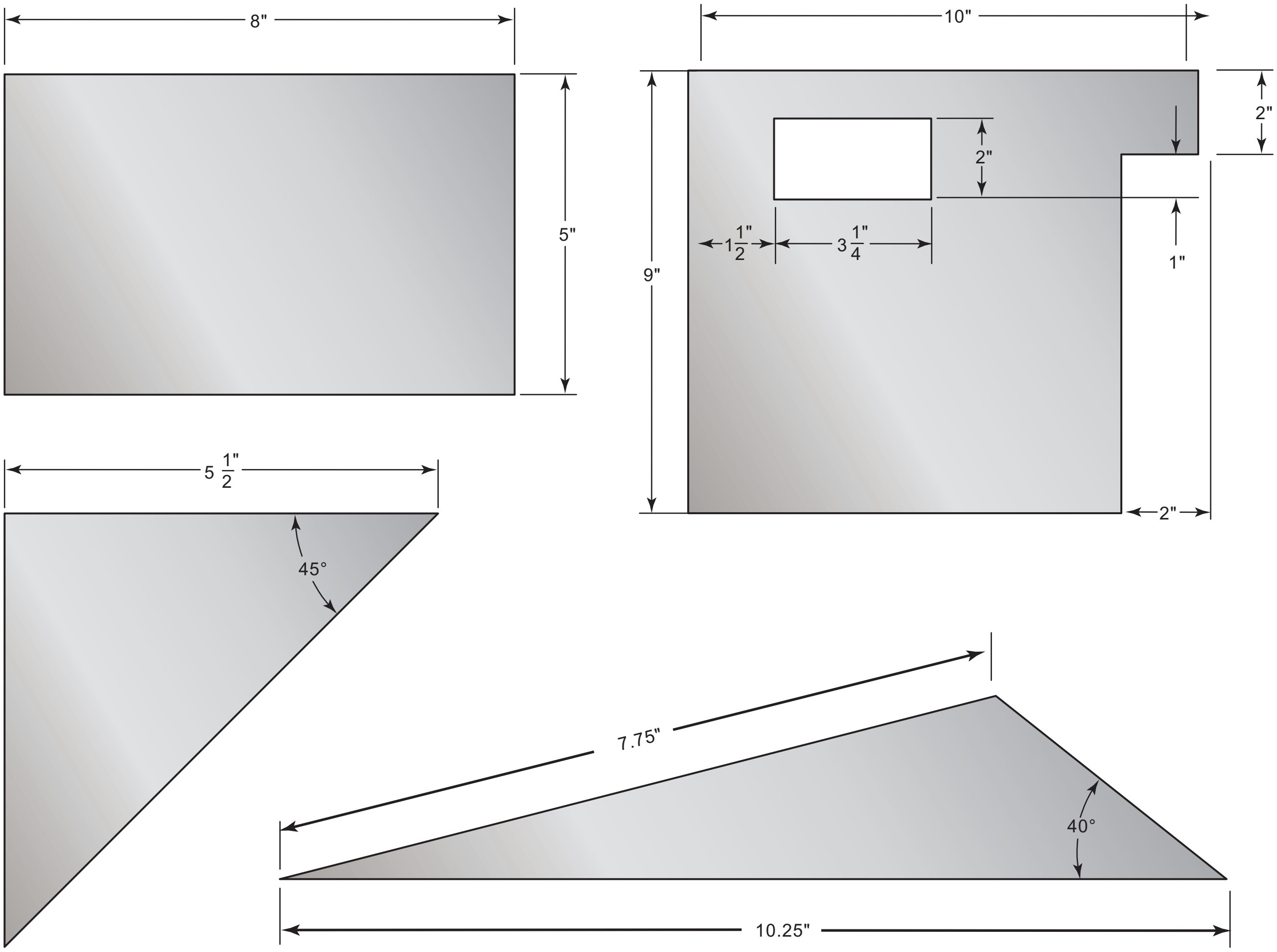


FIGURE 23-17 Lay out parts for Practice 23-1.

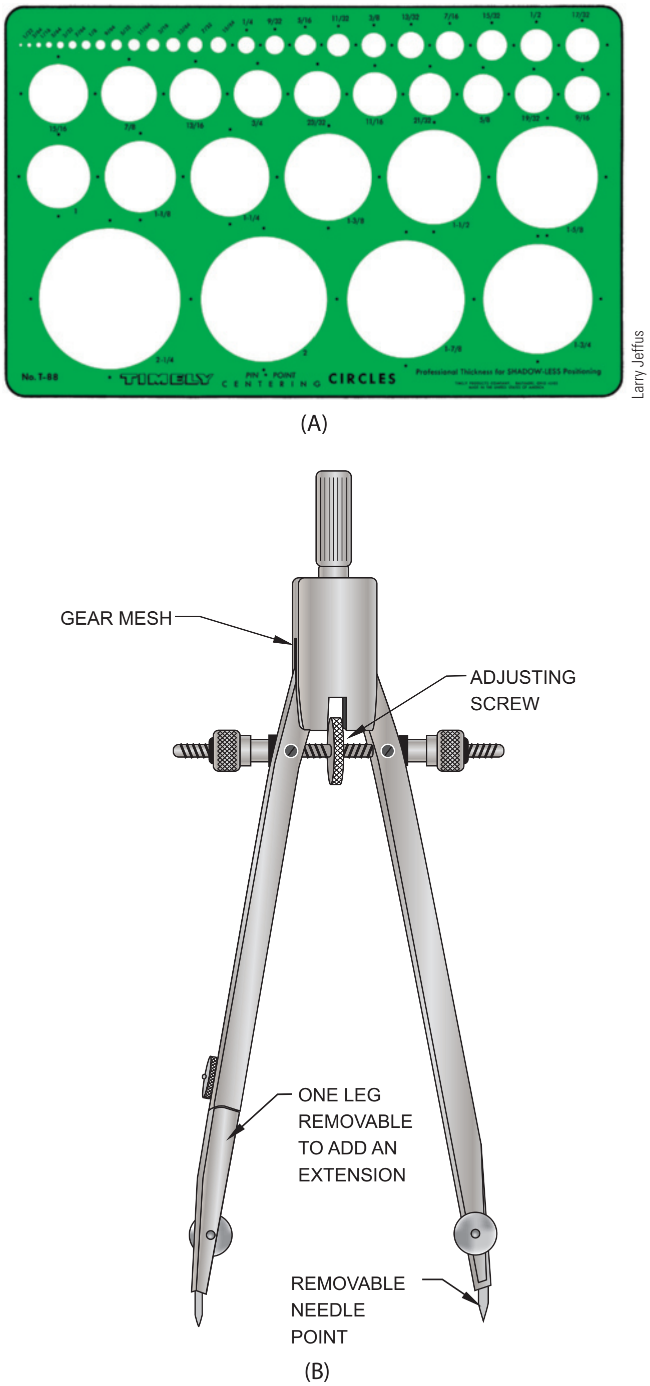


FIGURE 23-18 (A) Circle template. (B) Compass.

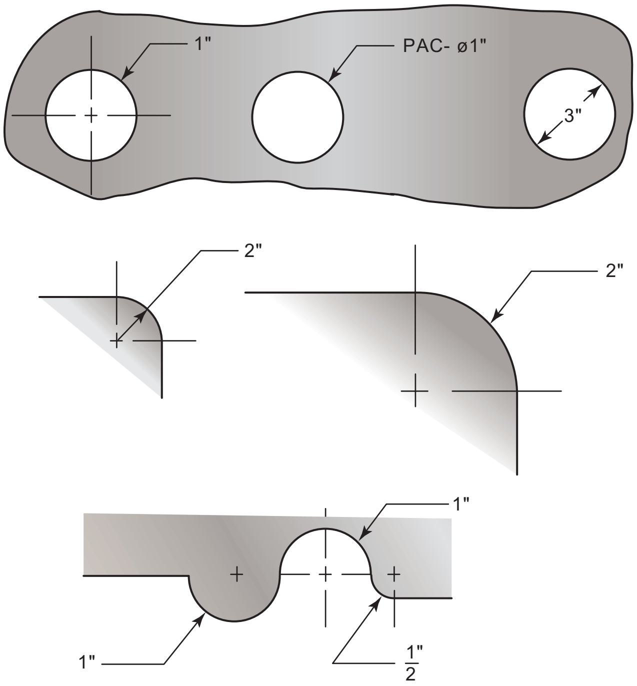


FIGURE 23-19 Dimensioning for arcs, curves, radii, and circles.

PRACTICE 23-2

Laying Out Circles, Arcs, and Curves

Using a piece of metal or paper, soapstone or pencil, tape measure, compass, or circle template and square, you will lay out the parts shown in **Figure 23-20**. The parts must be laid out within ± 1/16 in. of the dimensions. Convert the dimensions into SI metric units of measure.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

Nesting

Laying out parts so that the least amount of scrap is produced is important. Oddly shaped parts and parts with unusual sizes often produce the largest amount of scrap. Computers can be used to lay out nested parts with a minimum of scrap. Some computerized cutting machines can also be programmed to nest parts.

Manual nesting of parts may require several tries at laying out the parts to achieve the lowest possible scrap. On any cuts other than straight lines it is important to leave some material between parts. This material helps control the cut and prevents the cut from being interrupted or blowing out part of the metal, **Figure 23-21**. Even the finest laser cuts require that a small piece of scrap be laid out between parts.

PRACTICE 23-3

Nesting Layout

Using metal or paper that is 8 1/2 in. × 11 in., soapstone or pencil, tape measure, and square, you will lay out the parts shown in **Figure 23-22** in a manner that will result in the least scrap; assume a 0-in. kerf width. Use as many 8 1/2-in. × 11-in. pieces of stock as would be necessary to produce the parts using your layout. The parts must be laid out within ± 1/16 in. of the dimensions. Convert the dimensions into SI metric units of measure.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

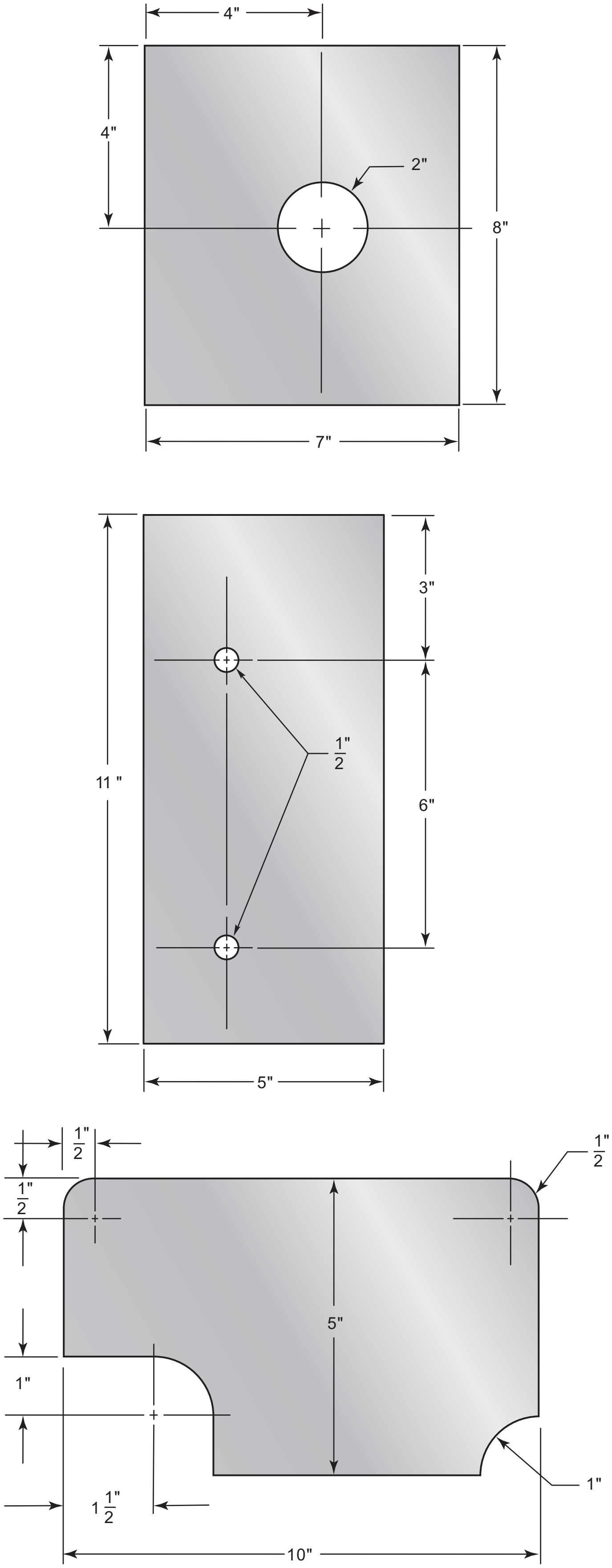


FIGURE 23-20 Lay out parts for Practice 23-2.

FIGURE 23-21 Parts nested for cutting; note the small blank space left between the parts.

PRACTICE 23-4

Bill of Materials

Using the parts laid out in Practice 23-3 and paper and pencil, you will fill out the bill of materials form shown in **Table 23-1**.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

KERF SPACE

Because all cutting processes, except for some shearing, produce a kerf during the cut, this space must be included in the layout when parts are laid out side by side. Many angle iron cutting shears remove a thin strip of metal so that both sides of the cut are square, **Figure 23-23**. The **kerf** is the space created as material is removed during a cut. The width of a kerf varies depending on the cutting process used. Of the cutting processes used in most shops, the metal saw will produce one of the smallest kerfs and the handheld oxyfuel cutting torch can produce one of the widest.

When only one or two parts are being cut, the kerf width may not need to be added to the part dimension. This space may be taken up during assembly by the root gap required for a joint. If a large number of parts are being cut out of a single piece of stock, then the kerf width can add up and increase the stock required for cutting out the parts, **Figure 23-24**.

PRACTICE 23-5

Allowing Space for the Kerf

Using a pencil, 8 1/2-in. × 11-in. paper, measuring tape or rule, and square, you will lay out four rectangles 2 1/2 in. × 5 1/4 in. down one side of the paper, leaving 3/32 in. for the kerf.

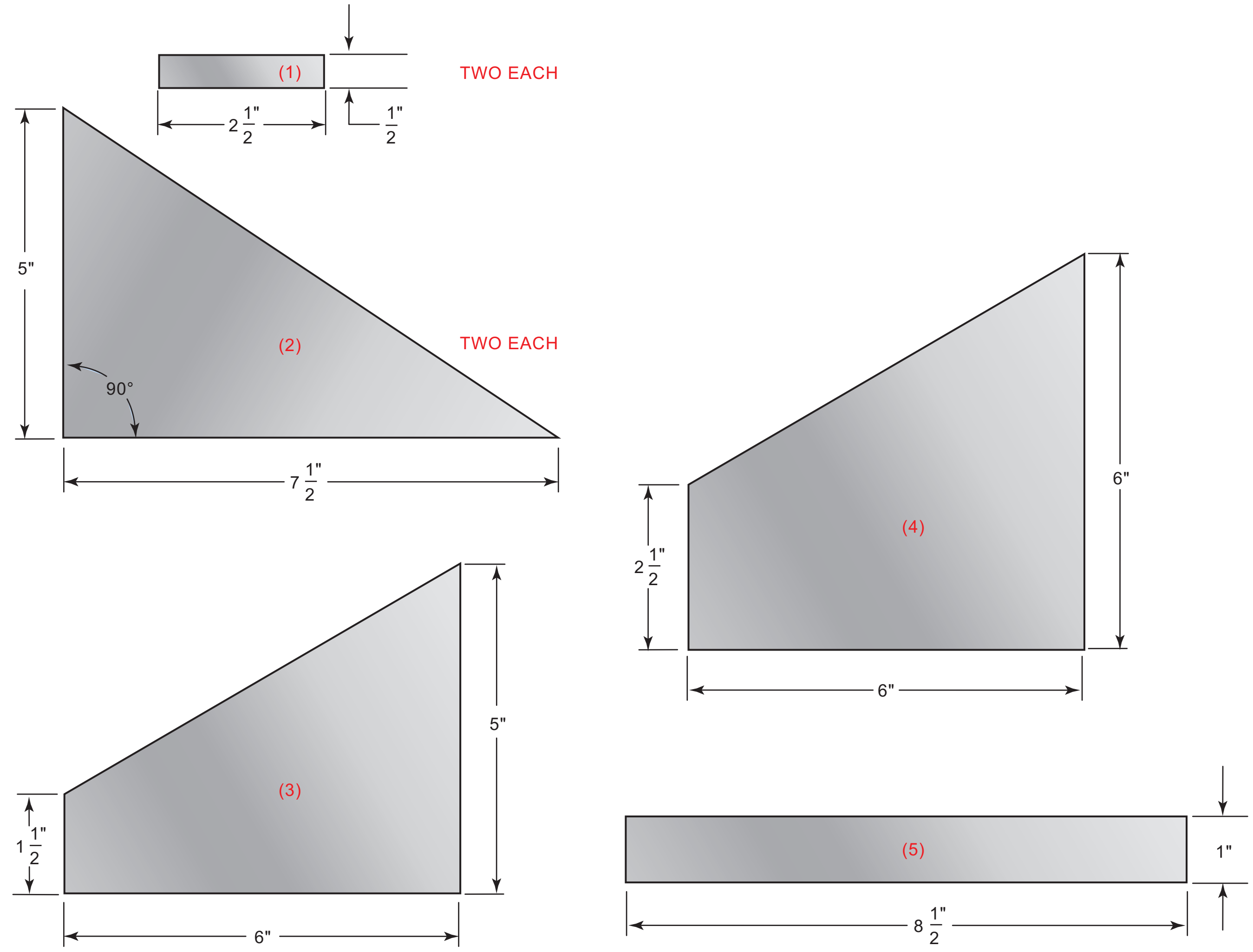


FIGURE 23-22 Parts to be nested.

Part	Number Required	Type of Material	Size (Standard Units)	(SI Units)
Base	1	Hot-roll steel	1/2″ × 5″ × 8″	12.7 mm × 127 mm × 203.2 mm
Cleat	2	Hot-roll steel	1/2″ × 4″ × 8″	12.7 mm × 101.6 mm × 203.2 mm

TABLE 23-1 Bill of Materials Form

Two methods can be used to provide for the kerf spacing. One method is to draw a double line on the side of the part where the kerf is to be made, **Figure 23-25**. The other way is to lay out a single line and place an *X* on the side of the line on which the cut is to be made, **Figure 23-26**. Note that no kerf space needs to be left along the sides made next to the edge of the paper or next to the scrap. What is the total length and width of material needed to lay out these four parts?

Parts can be laid out by tracing either an existing part or a template, **Figure 23-27**. When using either process, be sure the line you draw is made as tight as possible to the part's edge, **Figure 23-28**. The inside edge of the line is the exact size of the part. Make the cut on the line or to the outside so that the part will be the correct size once it is cleaned up, **Figure 23-29**. Sometimes a template is made of a part. Templates are useful if the part is complex and needs to fit into an existing weldment. They are also helpful when a large number of the same part is to be made or when the part is only occasionally used. The advantage of using templates is that once the detailed layout work is completed, exact replicas can be made anytime

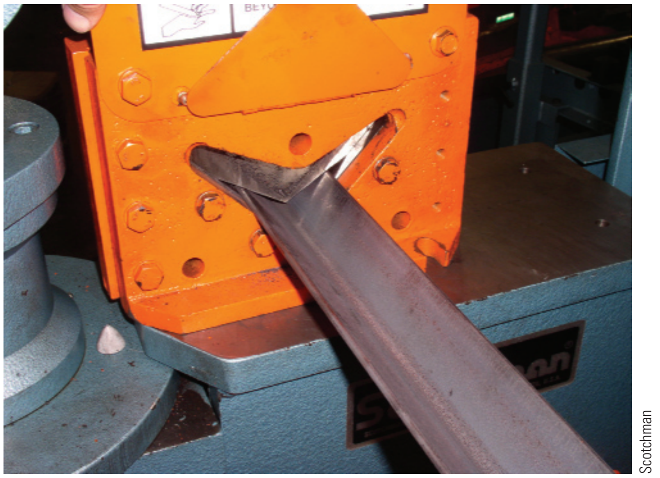


FIGURE 23-23 Angle iron shear.

they are needed. Templates can be made out of heavy paper, cardboard, wood, sheet metal, or other appropriate material. The sturdier the material, the longer the template will last.

Special tools have been developed to aid in laying out parts; one such tool is the **contour marker**, **Figure 23-30**. These markers are highly accurate when properly used, but they do require a certain amount of practice. Once familiar with this tool, the user can lay out an almost infinite variety of joints within the limits of the tool being used. One advantage of tools like the contour marker is that all sides of a cut in structural shapes and pipe can be laid out from one side without relocating the tool, **Figure 23-31**.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

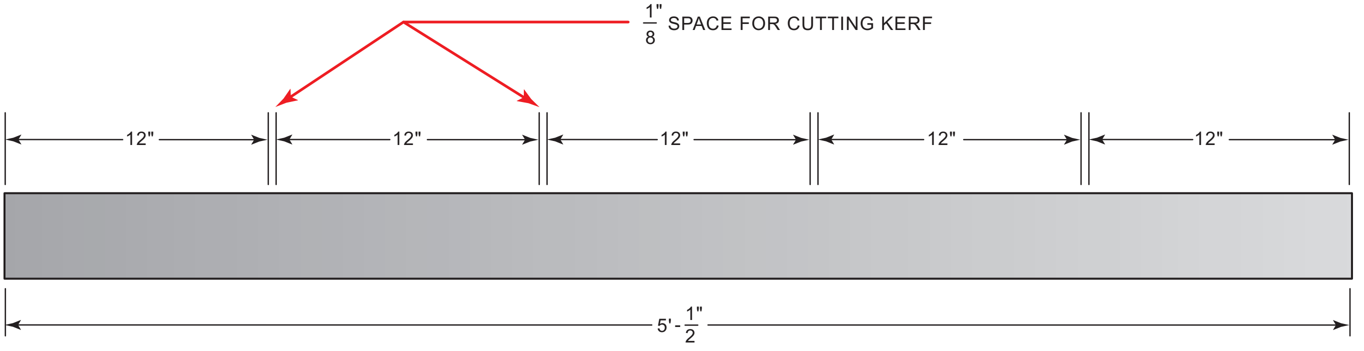


FIGURE 23-24 Because of the kerf, an additional 1/2 in. (13 mm) of stock would be required to make these five 1-ft pieces.

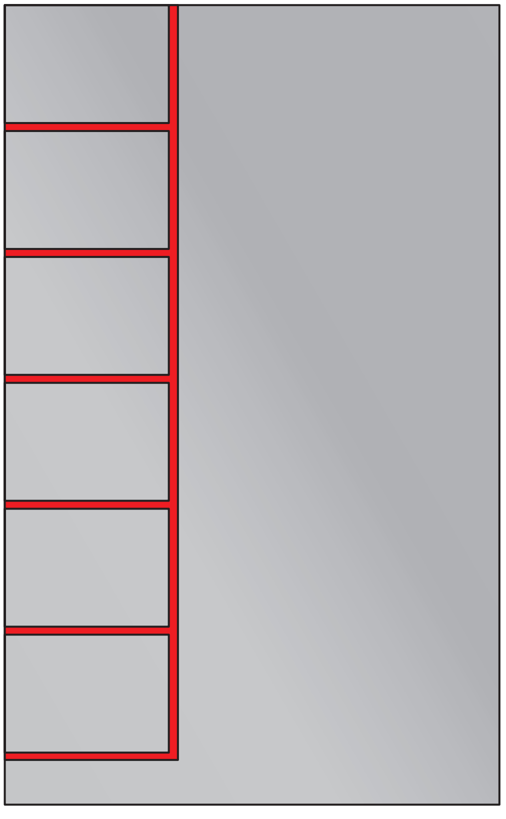


FIGURE 23-25 Kerf is made between the lines.

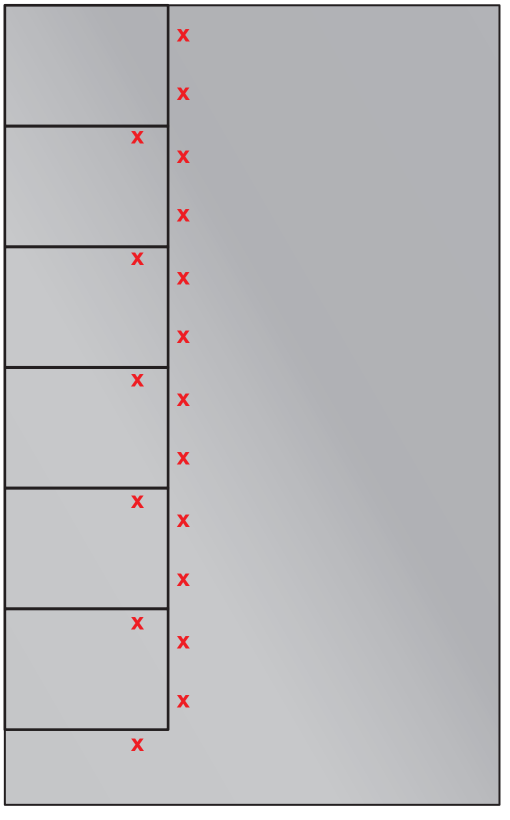
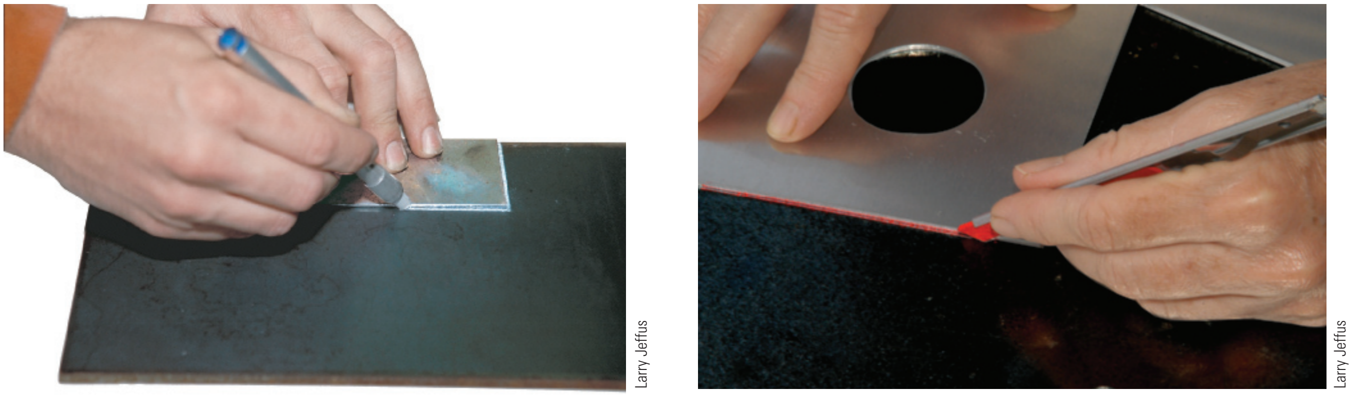


FIGURE 23-26 Xs mark the side of the line on which the kerf is to be made.



(A) (B)

FIGURE 23-27 (A) Tracing a part. (B) Using a straightedge to make a line.

FIGURE 23-28 Be sure that the soapstone is held tightly into the part being traced.

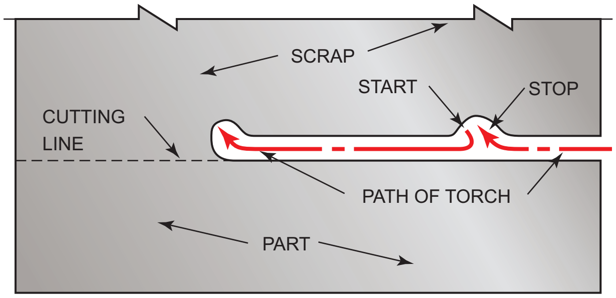


FIGURE 23-29 Turning out into scrap to make stopping and starting points smoother.

FIGURE 23-30 Pipe lateral being laid out with contour marker.

MATERIAL SHAPES

Metal stock can be purchased in a wide variety of shapes, sizes, and materials. Weldments may be constructed from combinations of sizes and/or shapes of metals. Only a single type of metal is usually used in most weldments,

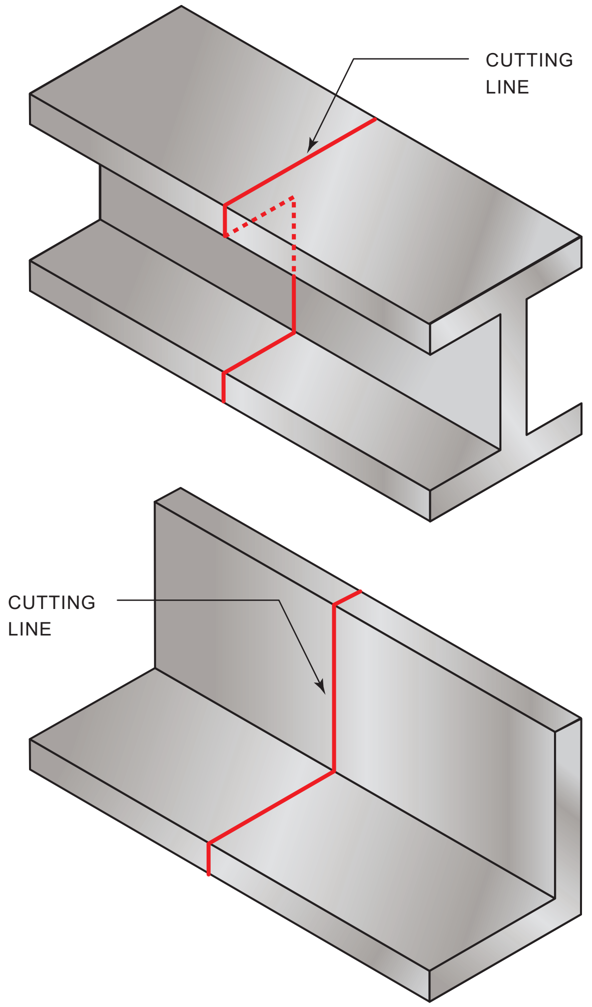


FIGURE 23-31 Layout for structural shapes.

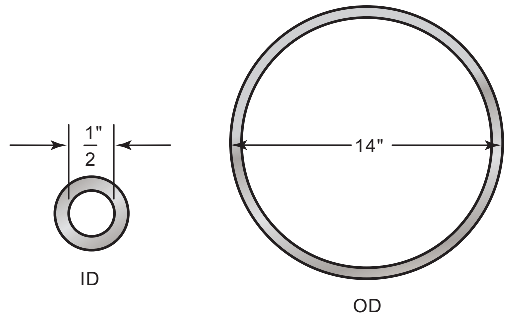


FIGURE 23-32 Inside diameter (ID) and outside diameter (OD).

unless a special property such as corrosion resistance is needed. In those cases, dissimilar metals may be joined into the fabrication at such locations as needed. The most common metal used is carbon steel, and the most common shapes used are plate, sheet, pipe, tubing, and angles. For that reason, most of the fabrication covered in this chapter concentrates on carbon steel in those commonly used shapes. Transferring the fabrication skills learned in this chapter to the other metals and shapes should require only a little practice time.

BILL OF MATERIALS FORM

Plate is usually 3/16 in. (4.8 mm) or thicker and measured in inches and fractions of inches. Plates are available in widths ranging from 12 in. (305 mm) up to 96 in. (2438 mm) and lengths from 8 ft (2.4 m) to 20 ft (6 m). Thickness ranges up to 12 in. (305 mm).

Sheets are usually 3/16 in. (4.7 mm) or less and measured in gauge or decimals of an inch. Several different gauge standards are used. The two most common are the Manufacturer's Standard Gauge for Sheet Steel, used for carbon steels, and the American Wire Gauge, used for most nonferrous metals such as aluminum and brass.

Pipe is dimensioned by its diameter and schedule or strength. Pipe that is smaller than 12 in. (305 mm) is dimensioned by its inside diameter, and the outside diameter is given for pipe that is 12 in. (305 mm) in diameter and larger, **Figure 23-32**. The strength of pipe is given as a schedule. Schedules 10 through 180 are available; schedule 40 is often considered a standard strength. The wall thickness for pipe is determined by its schedule (pressure range). The larger the diameter of the pipe, the greater its area. Pipe is available as welded (seamed) or extruded (seamless).

Tubing sizes are always given as the outside diameter. The desired shape of tubing, such as square, round, or rectangular, must also be listed with the ordering information.

The wall thickness of tubing is measured in inches (millimeters) or as Manufacturer's Standard Gauge for Sheet Metal. Tubing should also be specified as rigid or flexible. The strength of tubing may also be specified as the ability of tubing to withstand compression, bending, or twisting loads.

Angles, sometimes referred to as angle iron, are dimensioned by giving the length of the legs of the angle and their thickness, **Figure 23-33**. Stock lengths of angles are 20 ft, 30 ft, 40 ft, and 60 ft (6 m, 9.1 m, 12.2 m, and 18.3 m).

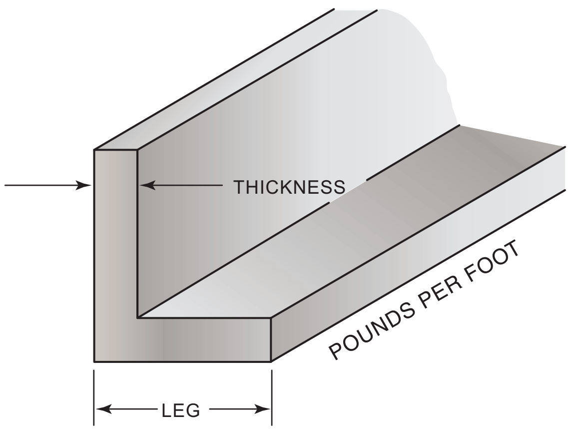


FIGURE 23-33 Specifications for sizing angles.

OVERALL TOLERANCE

When fabricating a weldment that is made up of a number of parts all welded together, there is a potential problem that the overall size of the weldment can be wrong. Every part manufactured has a tolerance. **Tolerance** is the amount that a part can be bigger or smaller than it should be and still be acceptable. The more exact a part's tolerance, the more time it takes to make and, therefore, the more it costs. In most cases, welding engineers have calculated the effect of these slight variations in size when they designed a weldment. As the weldment fabricator, you must take these tolerances into consideration as you make the assembly to ensure that the overall size of the weldment is within its tolerance.

As the number of parts that make up a weldment increases, the problem of compounding the errors increases. For example, if there are eight parts and each part is 1/8 in. larger than its ideal size but within its ± 1/8 in. tolerance, then the overall length of the finished weldment could be 8/8ths or 1 in. too long. Likewise, if each of the parts were 1/8 in. shorter, then the overall length would be 1 in. too short, **Figure 23-34**. Therefore, an assembler must be mindful of both the size of each part and the overall size of the assembly. In addition to tolerances for size, parts also have angle tolerances. For example, each of the 10 pieces that comprise the star in **Figure 23-35** are off by only 1°. But as you can see when they are assembled, the last corner does not fit, making the weldment unacceptable.

Ideally, all the parts for a weldment fit up perfectly; however, in reality that does not always happen. You cannot just throw out all of the parts that do not fit to find the ones that would make the perfect star. That is especially true if the parts are made within the correct tolerance. When parts like the ones in this star are made on the shorter side of the tolerance, you might be able to "loosen up" the joint tolerance to make the overall star work. Welded joints, like parts, have tolerances. By slightly adjusting the alignment of each of the 10 pieces, the star can be made within its overall acceptable tolerance. In this case, by making sure all the joints stay within tolerance, the complete star can be made without having to recut any of the parts. If you can make this assembly by adjusting the joint tolerance, you can assemble it faster; and because each of the parts is exactly the same, it will look perfect, Figure 23-35.

Whenever possible, try to get the parts to fit without having to recut or grind them; however, remember that the finished weldment must be within tolerance. You want to avoid recutting and grinding because both will add time and cost to the finished project. However, you must remember that in some cases, the only way the weldment can be assembled within overall tolerance is to recut or grind some or all of the parts. If the finished weldment is not within tolerance, then it may be unusable. If you must grind a part to fit, try to do as little grinding as possible to get the parts to fit up. Grinding by hand is a time-consuming operation, and as Benjamin Franklin once said, "Remember that time is money."

Where you recut or grind a part can sometimes greatly affect the time required. For example, if the pieces used in the star need to be ground to fit, you might want to grind along the short side, which would be faster, **Figure 23-36A**. In addition, it might be possible to grind only part of the edge to get the parts to fit up within tolerance. In the case of the parts shown in **Figure 23-36B**, the required root opening tolerance of 1/4 in. ± 1/8 in. will allow the part's edge to be ground unevenly as long as the root opening tolerance is maintained, **Figure 23-36C**. Note how the root opening varies but stays within the acceptable tolerance. The root opening is 1/4 in. at one end, which is acceptable; however, at the point where it becomes too close (less than 1/8 in.), begin grinding. The result as shown in **Figure 23-36D** meets the part's fit-up specifications and requires a minimum amount of grinding.

If the root opening is too wide, you may be able to make the weld, but it would be too large. Larger welds result in more filler metal being added and more heat input to the base metal. Larger welds may cause greater weld distortion and have larger heat-affected zones. Both can result in a

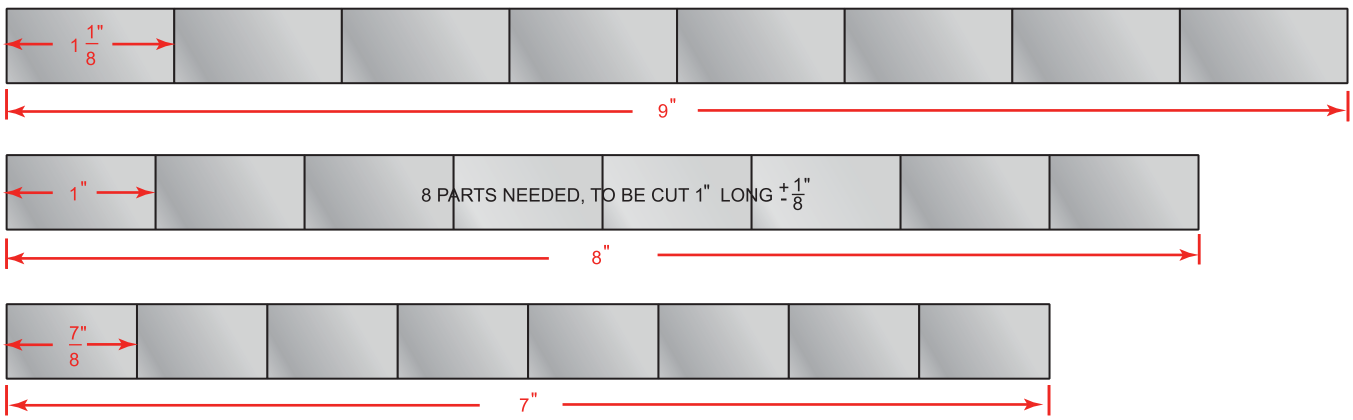


FIGURE 23-34 Lay out parts to avoid compounding dimensioning errors.

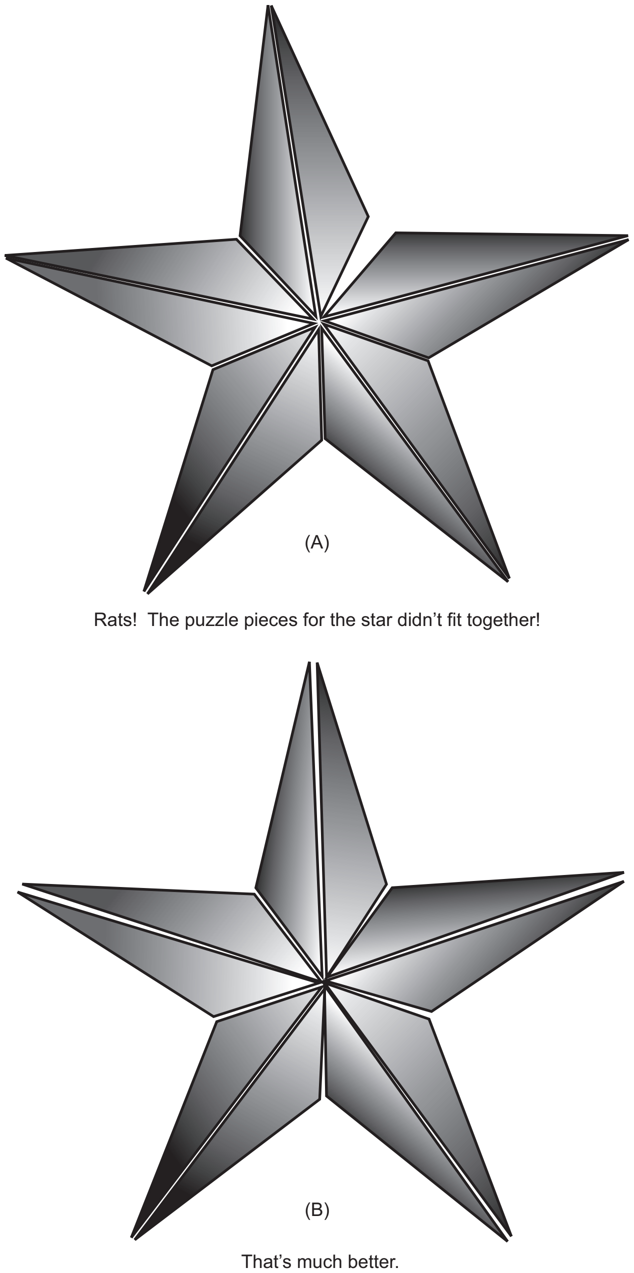


FIGURE 23-35 Small errors on lots of parts can become a big error on the finished assembly.

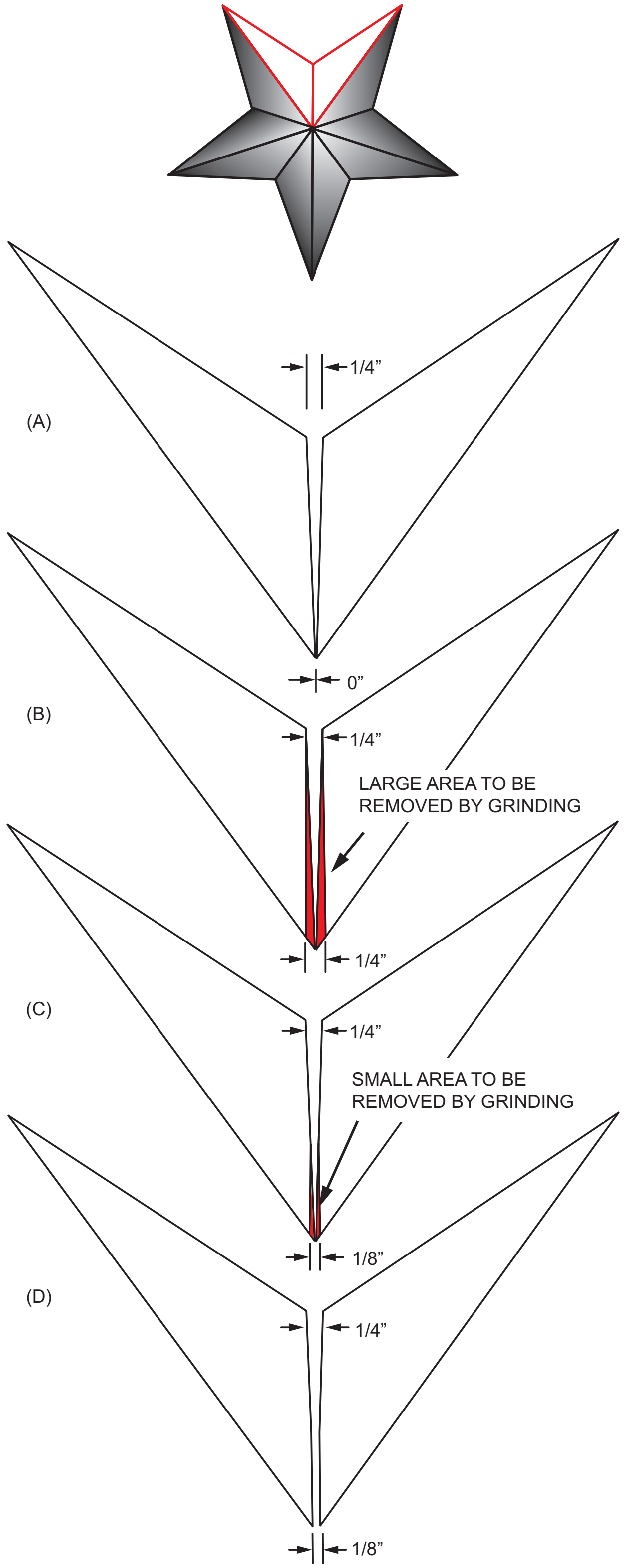


FIGURE 23-36 Trimming parts efficiently can save time.

weld that will not withstand the part's designed strength specifications.

Even a quick visual inspection by a welding inspector would tell that the weld is unacceptable and must be repaired. You cannot deviate beyond the tolerance for the root opening as specified in the welding procedure; to do so is wrong.

ASSEMBLY

The assembling process, bringing together all the parts of the weldment, requires a proficiency in several areas. You must be able to read the drawing and interpret the information provided there to properly locate each part. An assembly drawing has the necessary information, both graphically and dimensionally, to allow the various parts to be properly located as part of the weldment. If the assembly drawings include either pictorial or exploded views, this process is much easier for the beginning assembler; however, most assembly drawings are done as two, three,

or more orthographic views, **Figure 23-37**. Orthographic views will be more difficult to interpret until you have developed an understanding of their various elements.

On very large projects such as buildings or ships, a corner or centerline is established as a baseline. This is the point where all measurements for all part locations begins. When working with smaller weldments, a single part may be selected as such a starting point. Often, selecting the base part is automatic because all other parts are to be joined to this central part. On other weldments, however, the selection of a base part is strictly up to the assembler.

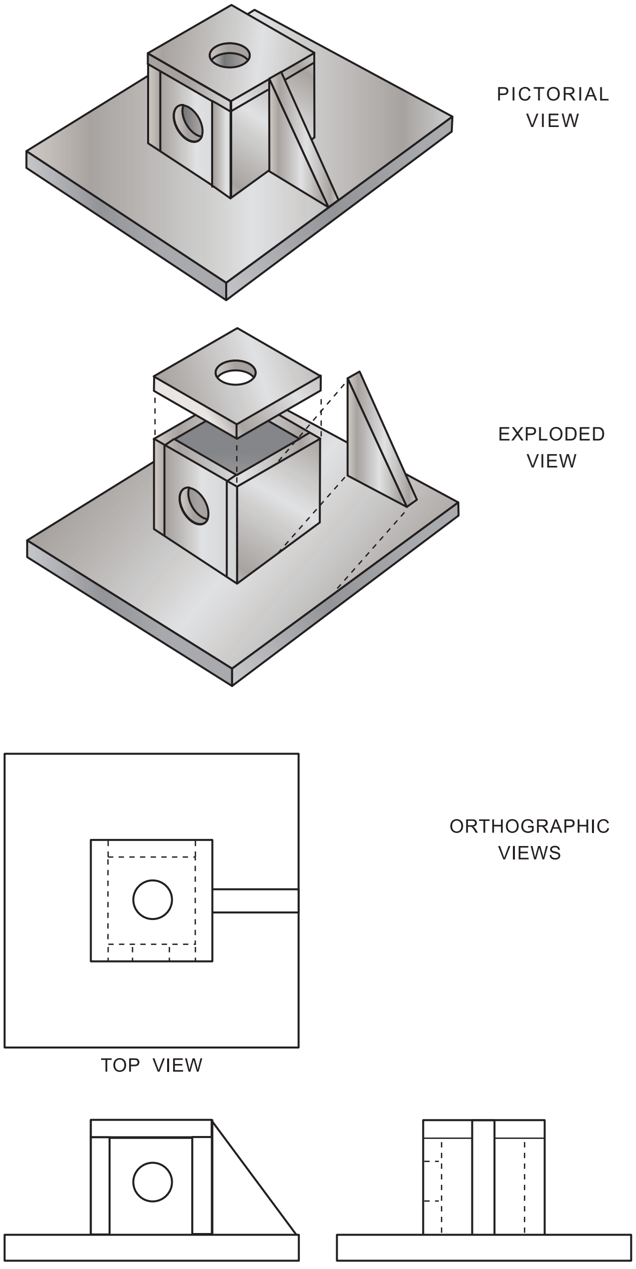


FIGURE 23-37 Types of drawings that can be used to show a weldment assembly.

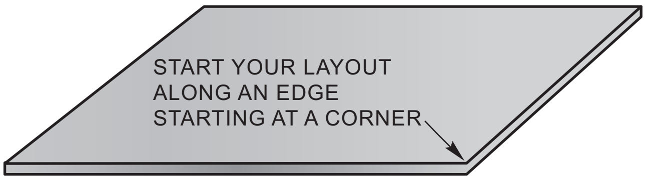


FIGURE 23-38 Laying out parts squarely is easier when they are placed along an edge or at the corner of the plate.

To start the assembly, select the largest or most central part to be the base for your assembly. All other parts will then be aligned to this one part. When possible, use the edge or corner as the base or starting point for locating parts because it makes alignment easier, **Figure 23-38**. A base also helps to prevent location and dimension errors. Otherwise, a slight misalignment of one part, even within tolerances, will be compounded by the misalignment of other parts, resulting in an unacceptable weldment. Using a baseline or base part will result in a more accurate assembly.

You must look at the drawing to see how the edges are fitted. This is much more important on thicker materials than it is with thin stock, **Figure 23-39A**. Of course, even on thin material it can be important if the part is to be built to a very tight tolerance. In that case, if the joint should be assembled as shown in Figure 23-39A but is assembled as shown in **Figure 23-39B**, then the overall length in one direction decreases by the thickness of the material; in the other direction, the dimension increases by the thickness of the material.

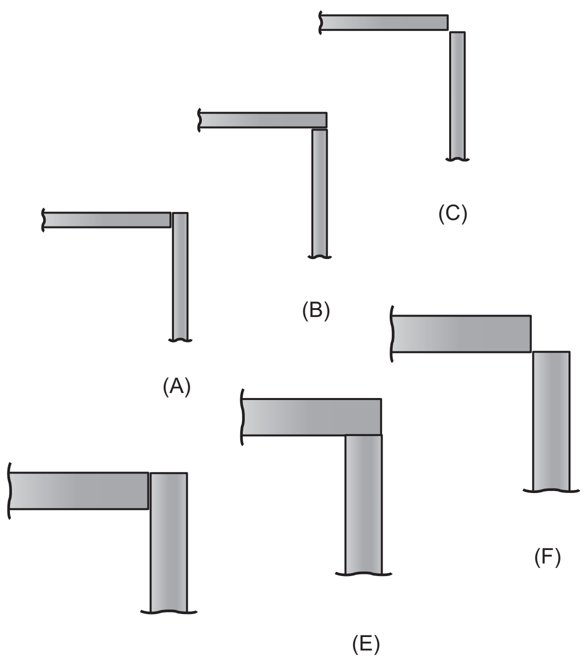
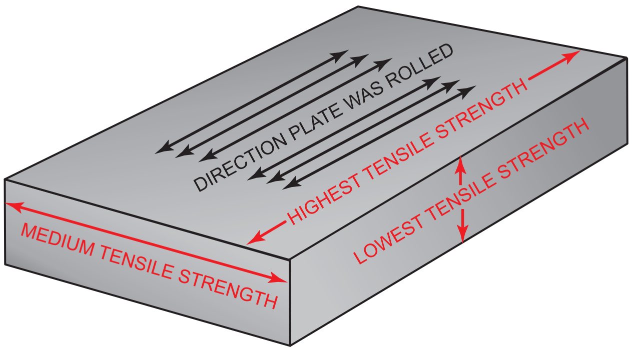


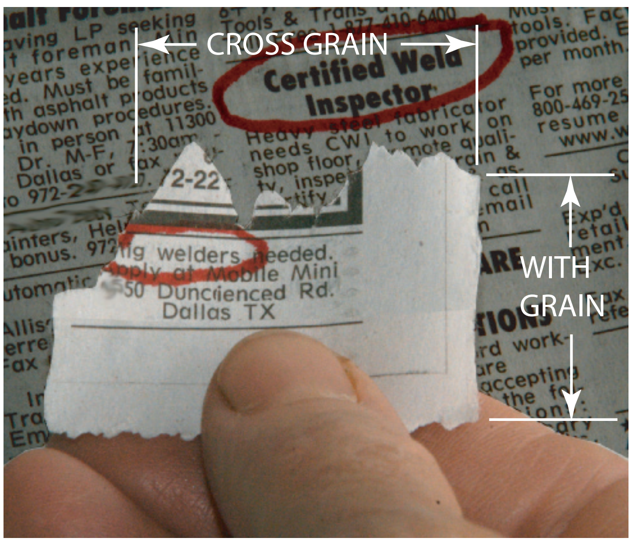
FIGURE 23-39 Part placement during assembly can affect the overall dimension, especially when the metal being assembled is thick.

Overall Dimensions and Thick Materials

On thicker materials it is easy to see how the overall dimensions of a weldment could change if the parts are not properly aligned during fit up. However, in addition to not being the correct size, sometimes the weld itself will not be as strong if the joint is not aligned properly. The reason the weld might not be as strong as it is designed to be is because the tensile strength of thick metal plate differs depending on the direction the load is placed on the plate as compared to the rolling direction of the plate, **Figure 23-40A**. Metal plate, much like wood, will break in one direction easier than in another. In this regard, steel plate is similar to a wooden board in that the direction of the rolled grain of a plate and the direction of the wood grain in a board affect their strength. Many common materials have a grain; for example, when you tear a newspaper down the page, it tears fairly easily and straight. However, when you try to tear it across the page, the tear is much more jagged, **Figure 23-40B**.



(A)



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(B)

FIGURE 23-40 (A) A metal's strength is affected by the direction it is rolled because of its grain structure. (B) The effect of grain structure can be seen on a newspaper as it is torn.

Part Identification

Identify each part of the assembly and mark each piece for future reference. If needed, you can hold the parts together and compare their orientation to the drawing. Locate points on the parts that can be easily identified on the drawing such as holes and notches, **Figure 23-41**. Now mark the location of these parts—top, front, or other such orientation—so you can locate them during the assembly.

Layout lines and other markings can be made on the base to locate other parts. Using a consistent method of marking will help prevent mistakes. One method is to draw parallel lines on both parts where they meet, **Figure 23-42**.

After the parts have been identified and marked, they can be either held or clamped into place. Holding the parts in alignment by hand for tack welding is fast but often leads to errors and thus is not recommended for beginning assemblers. Experienced assemblers recognize that clamping the parts in place before tack welding is a much more accurate method, **Figure 23-43**.

ASSEMBLY TOOLS

A variety of tools are used to make assembly easier. Both general tools and job-specific assembly tools are commonly used.

Clamps A variety of clamps can be used to temporarily hold parts in place so that they can be tack welded.

- *C-clamps*, one of the most commonly used clamps, come in a variety of sizes, **Figure 23-44**. Some C-clamps have been specially designed for welding. Some of these clamps have a spatter cover over the screw, and others have their screws made of spatter-resistant materials such as copper alloys.
- *Bar clamps* are useful for clamping larger parts. Bar clamps have a sliding lower jaw that can be positioned against the part before tightening the screw-clamping end, **Figure 23-45**. They are available in a variety of lengths.
- *Pipe clamps* are very similar to bar clamps. The advantage of pipe clamps is that the ends can be attached to a section of standard 1/2-in. (13 mm) pipe. This feature allows for greater flexibility in length, and the pipe can easily be changed if it becomes damaged.
- *Locking pliers* are available in a range of sizes with a number of various jaw designs, **Figure 23-46**. The versatility and gripping strength make locking pliers very useful. Some locking pliers have a self-adjusting feature that allows them to be moved between different thicknesses without the need to readjust them.
- *Cam-lock clamps* are specialty clamps that are often used in conjunction with a jig or a fixture. They can be preset, allowing for faster work, **Figure 23-47**.
- *Specialty clamps* such as those used for pipe welding, **Figure 23-48**, are available for many different types of jobs. Such specialty clamps make it possible to do faster and more accurate assembling.

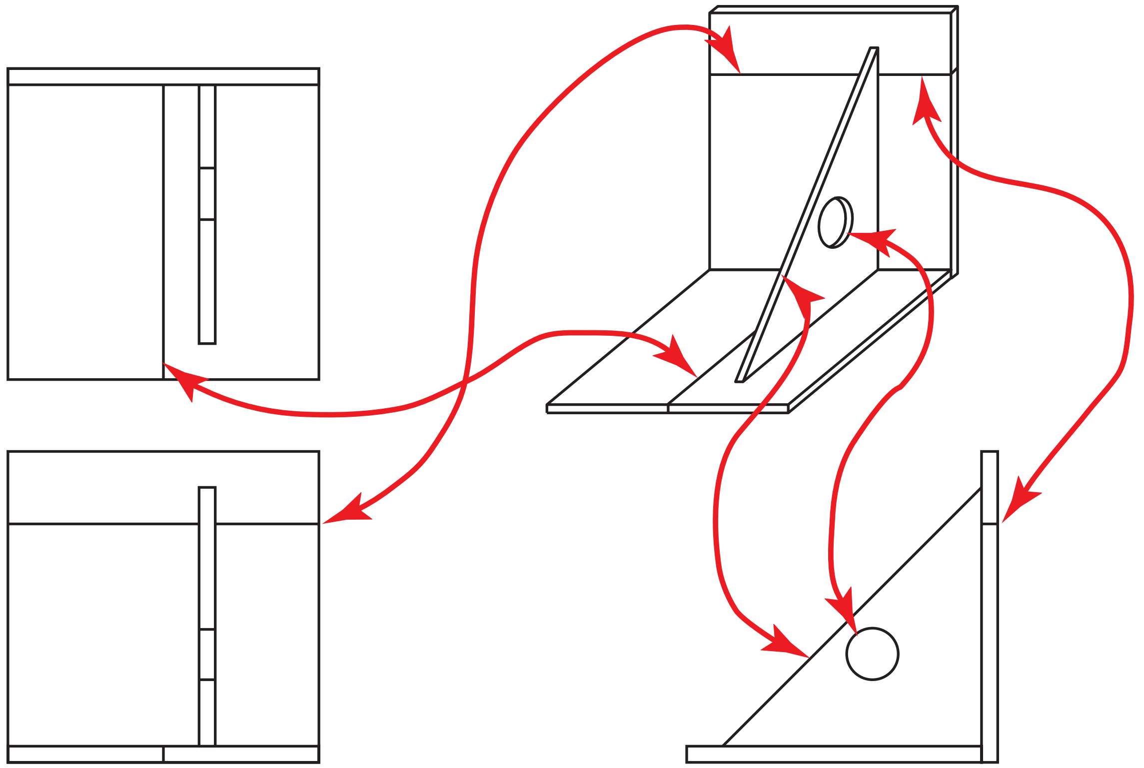


FIGURE 23-41 Identify unique points to aid in assembly.

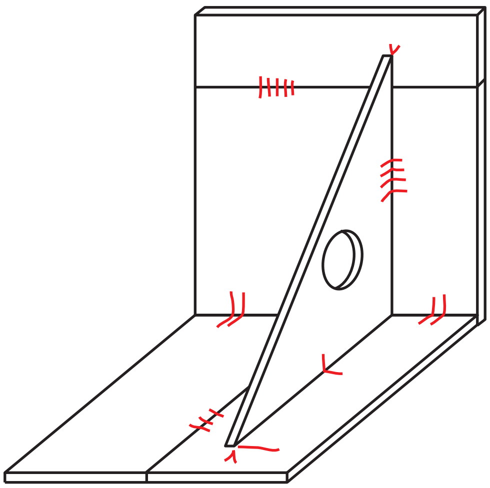


FIGURE 23-42 Lay out markings to help locate the parts for tack welding.

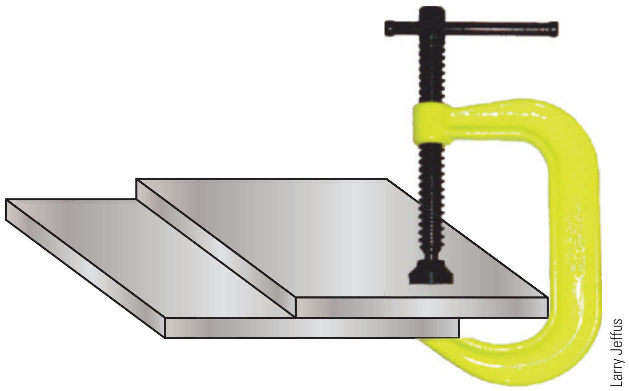


FIGURE 23-43 C-clamp being used to hold plates for tack welding.

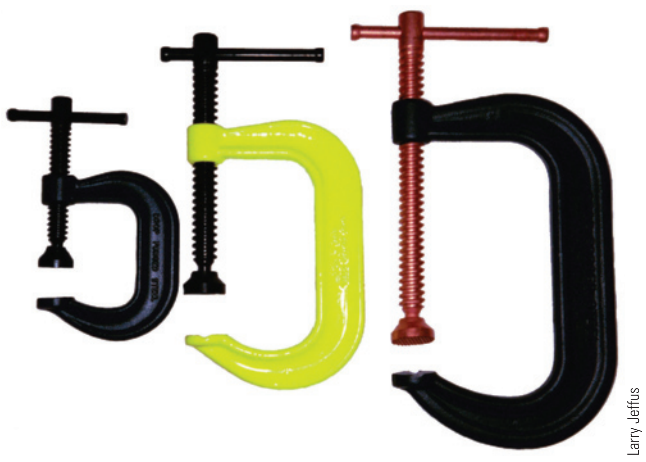
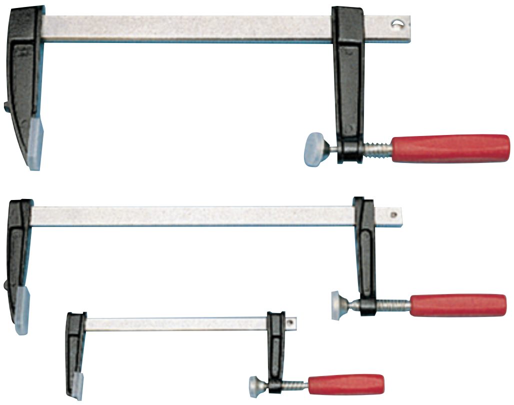


FIGURE 23-44 C-clamps come in a variety of sizes.

Fixtures **Fixtures** are devices that are made to aid in assemblies and fabrication of weldments. When a number of similar parts are to be made, fixtures are helpful. They can increase speed and accuracy in the assembly of parts. Fixtures must be strong enough to support the weight of the parts, must be able to withstand the rigors of repeated assemblies, and must remain in tolerance. They may have clamping devices permanently attached to speed up their use, **Figure 23-49**. Often, locating pins or other devices are used to ensure proper part location. A well-designed fixture allows adequate room for the welder to make the



Strong Hand Tools & Good Hand, Inc.

FIGURE 23-45 Bar clamps can be opened wider than most C-clamps to be used on larger weldments.

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FIGURE 23-46 Three common jaw types on locking pliers.

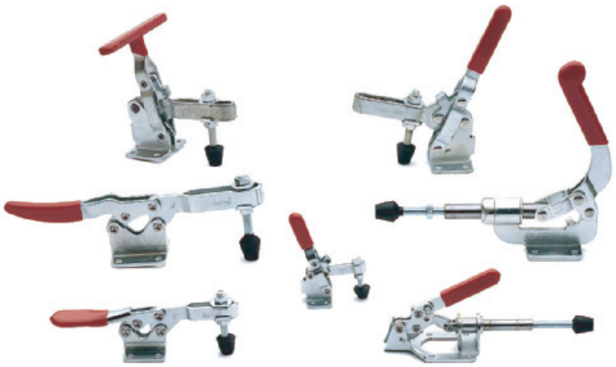

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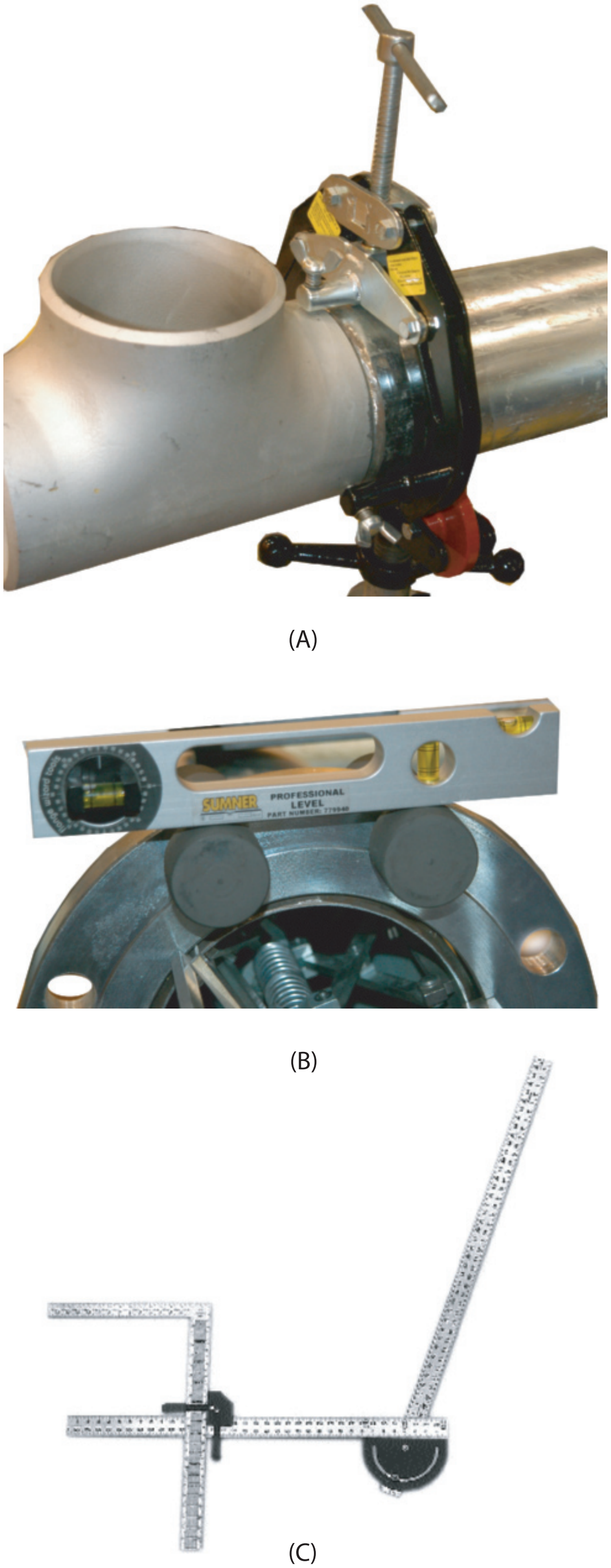
FIGURE 23-47 Toggle-type clamps.



(A)

(B)

(C)

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FIGURE 23-48 Specialty pipe clamps and alignment tools.

necessary tack welds. Some parts are left in the fixture through the entire welding process to reduce distortion. Making fixtures for every job is cost-prohibitive and not necessary for a skilled assembler.

FIGURE 23-49 Wooden jig holds the base plate in place while magnetic squares keep it aligned for welding.

FITTING

Fitting is the process of adjusting the parts of a weldment so that they meet the overall tolerance because not all parts fit exactly as they were designed. There may be slight imperfections in cutting or distortion of parts due to welding, heating, or mechanical damage. Some problems can be solved by grinding away the problem area. Hand grinders are most effective for this type of problem, **Figure 23-50**. Other situations may require that the parts be forced into alignment.

CAUTION

Never operate a hand grinder without the safety guard and eye protection.

A simple way of correcting slight alignment problems is to make a small tack weld in the joint and then use a hammer and possibly an anvil to pound the part into place, **Figure 23-51**. Small tacks applied in this manner will become part of the finished weld. Be sure not to strike the part in a location that will damage the surface and render the finished part unsightly or unusable.

More aligning force can be applied using cleats or dogs with wedges or jacks. Cleats or dogs are pieces of metal that are temporarily attached to the weldment's parts to enable

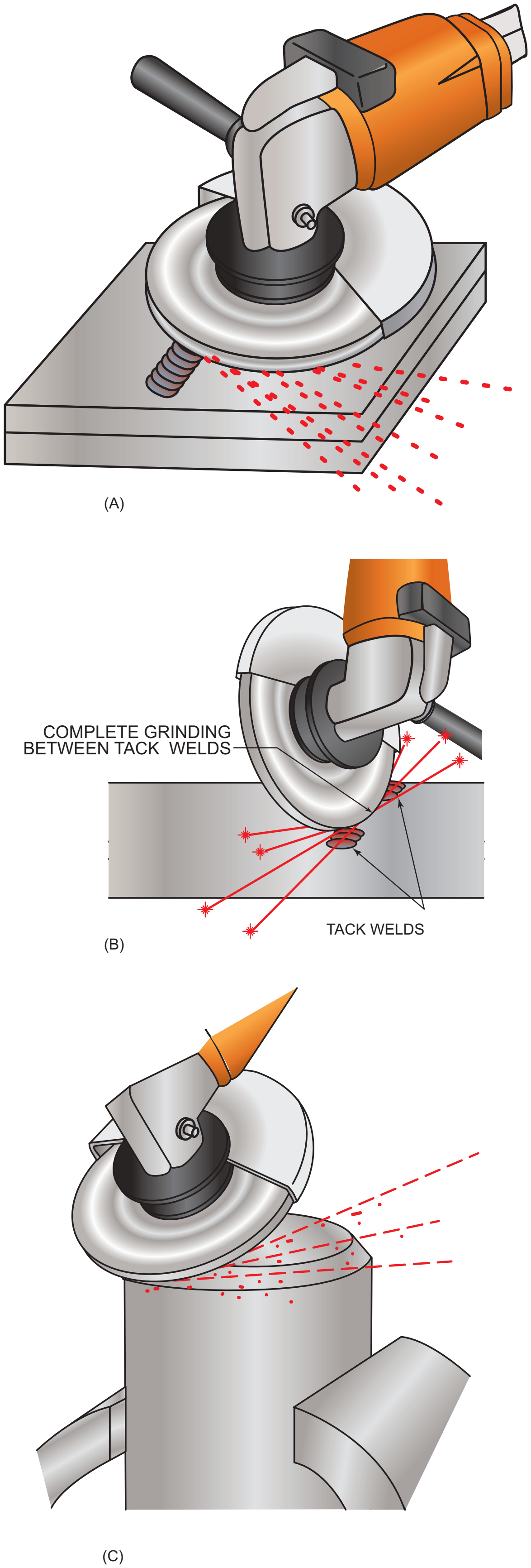

FIGURE 23-50 Abrasive grinding disk can be used to (A) remove excessive weld metal, (B) cut a groove, or (C) prepare a bevel for welding.

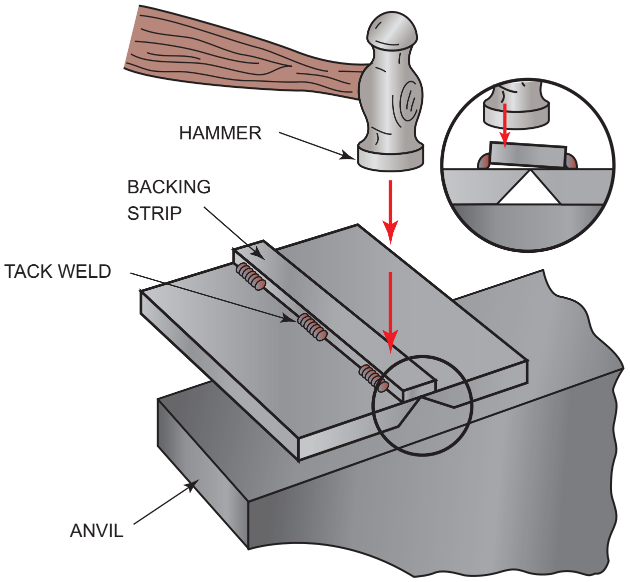

FIGURE 23-51 A hammer can be used to bend metal into alignment after a tack weld has been made.

them to be forced into place. Jacks will do a better job if the parts must be moved more than approximately 1/2 in. (13 mm), **Figure 23-52**. Any time cleats or dogs are used, they must be removed and the area must be ground smooth.

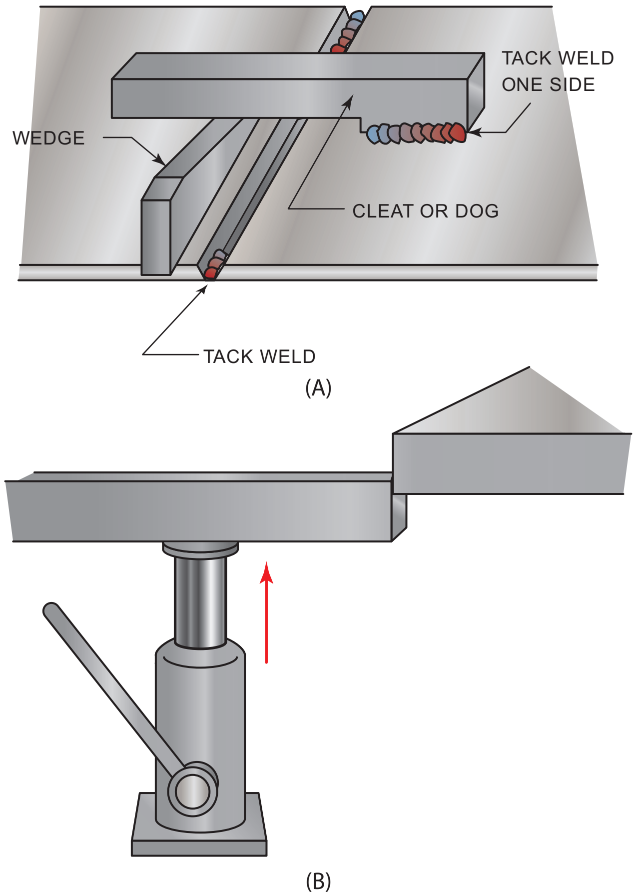

FIGURE 23-52 (A) Cleat and wedge used to align parts. (B) Hydraulic jack used to realign a part.

Some codes and standards will not allow cleats or dogs to be welded to the base metal. In these cases, more expensive and time-consuming fixtures must be constructed to help align the parts if needed.

TACK WELDS

Tack welds are welds (usually small in size) that are made during the assembly to hold all of the parts of a weldment together so the welding can be finished. Making good tack welds is one of the keys to assembly work. Tack welds must also be small enough to be incorporated into the final weld without causing a discontinuity in its size or shape, **Figure 23-53**. They must be strong enough to hold the parts in place for welding but small enough so they become an unseen part of the finished weld. Deciding on the number, size, and location of tack welds takes some planning. Following are some of the factors to consider regarding the number of tack welds:

- Thickness of the metal—A large number of very small tack welds should be used on thin metal sections, whereas a few large tack welds may be used for thicker metal parts.
- Length and shape of the joint—Obviously, short joints take fewer welds; however, some long, straight joints may have very few tack welds compared to a shorter joint that is very curvy.
- Welding stresses—All welds create stress in the surrounding metal as they cool and shrink. Larger welds produce greater stresses that might pull tack welds loose from an adjoining part if the tack welds are not strong enough to withstand the welding stresses, **Figure 23-54**.
- Tolerance—The more exacting the tolerance for the finished weldment, the more tack welds are required.
- Fit up—When custom-bending parts during the fit-up process, it may be necessary to use a large number of small tack welds to keep the parts in alignment and make the bends more uniform.

NOTE

Often it is necessary to change between wearing a welding helmet, cutting goggles, and safety shield as a part is being assembled. Whenever you take off your helmet, remember to place it face-up and not face-down. Placing your helmet face-up will prevent weld spatter, grinding sparks, and other shop dirt from collecting inside. If your helmet gets filled with debris, it will fall all over your head and face the next time you put it on. Keep your cutting goggles and safety shield face-up, too.

Tack welds must be made in accordance with any welding procedure with an appropriate filler metal.

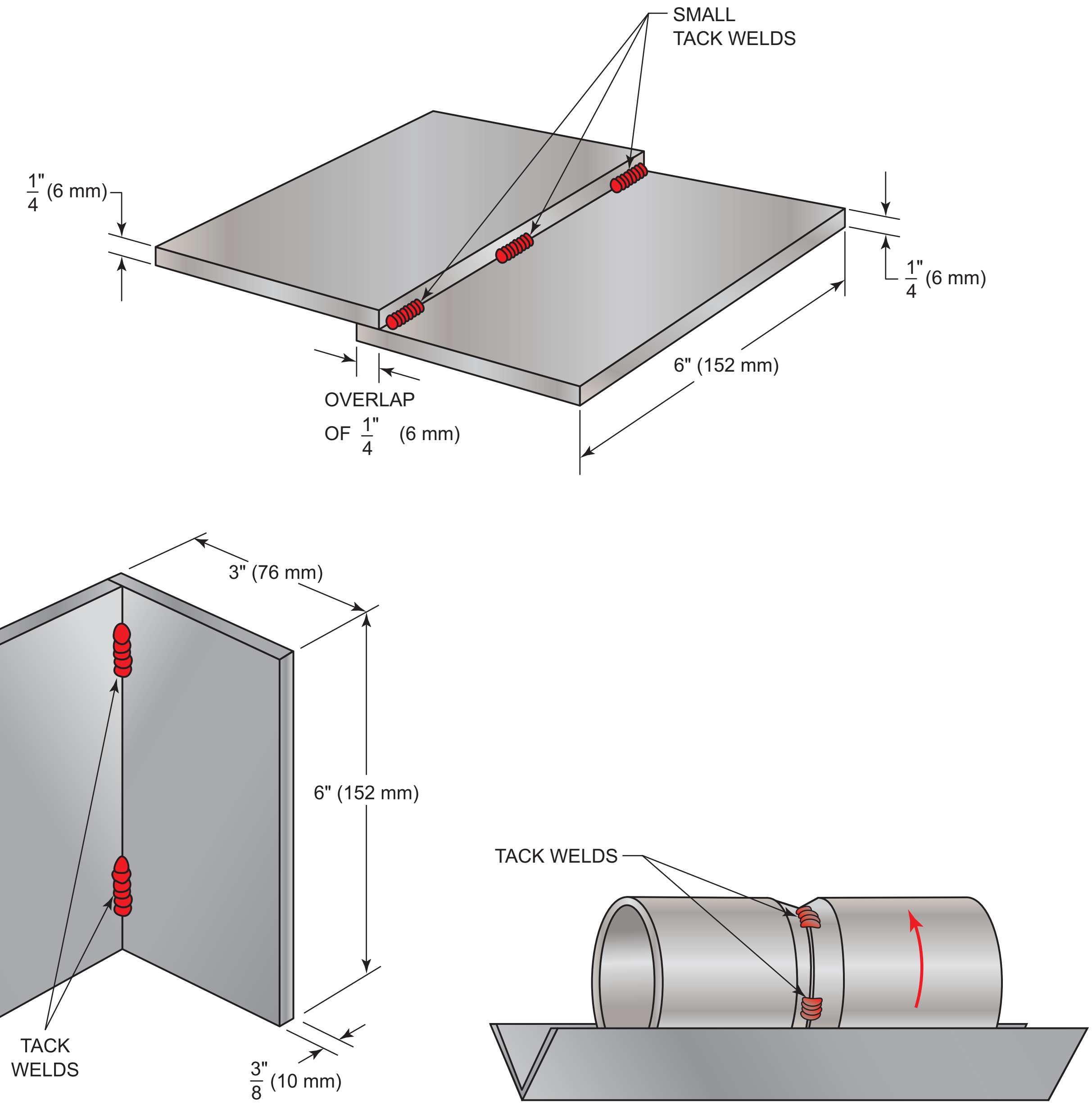

FIGURE 23-53 Make tack welds as small as possible.

FIGURE 23-54 Tack weld cracked due to welding stress.

They must be located well within the joint so that they can be completely remelted into the finished weld, **Figure 23-55**. Post-tack welding cleanup is required to remove any slag or impurities that may cause finished weld flaws. Sometimes the ends of a tack weld must be ground down to a taper to improve its tie-in to the finished weld metal.

Make sure that your tack welds are not going to be weld defects in the completed weldment. A good tack weld is one that does its job by holding parts in place yet is undetectable in the finished weld.

Do not assume that a broken tack weld has no effect and continue to weld. A broken tack can allow parts to shift well out of tolerance. On harder metals like steel you can often hear a tack weld break; however, for some soft metals like aluminum the tack weld may separate quietly.


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FIGURE 23-55 Tack weld made in line with the bolt hole so it will be out of the way when the flange is fitted.


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FIGURE 23-56 Bracing yourself using both hands and wearing auto-darkening helmets make tack welding easier and more accurate.

Depending on the type of metal and its size and thickness, a breaking tack weld can make a small sharp snap or deep resounding thump. You might hear one break while you are welding or sometime afterward. If you continue to weld, it may be impossible to pull the loose part back into position, which could result in the weldment not meeting its specifications. Sometimes this is referred to as "making scrap metal" and not a weldment.

WELDING

Good welding requires more than just filling up the joints with metal. The order and direction in which welds are made can significantly affect distortion in the weldment. Generally, welding on an assembly should be staggered from one part to another. This will allow both the welding heat and welding stresses to dissipate.

Arc Strikes

Keep the arc strikes in the welding joint so that they will be remelted as the weld is made. This will make the finished weldment look neater and reduce postweld cleanup. Some codes and standards do not allow arcs to be struck outside of the welding joint.

Striking the arc in the correct location on an assembly is more difficult than working on a welding table. When working on an assembly, you will often be in an awkward position, which makes it harder to strike the arc correctly. Several techniques will help you improve your arc-starting accuracy. You can use your free hand to guide the electrode or weld gun into the correct spot. Resting your arm, shoulder, or hip against the weldment can also help, **Figure 23-56**. Practicing starting the weld with the power off is sometimes helpful.

Be sure that you have enough freedom of movement to complete the weld joint. Check to see that your welding leads will not snag on anything that would prevent you from making a smooth weld. If you are welding out of position, be sure that welding sparks will not fall on you or other workers, **Figure 23-57**. If the weldment is too large to fit into a welding booth, then portable welding screens should be used to protect other workers in the area from sparks and welding light.

Follow all safety and setup procedures for the welding process. Practice the weld to be sure that the machine is set up properly before starting on the weldment.


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FIGURE 23-57 When making out-of-position welds, make sure to position yourself so that sparks and slag will not fall directly on you.

FINISHING

Depending on the size of the shop, the welder may be responsible for some or all of the finish work. Such work may vary from chipping, cleaning, or grinding the welds to applying paint or other protective surfaces.

Grinding of welds should be avoided if possible by properly sizing the weld as it is made. Grinding can be an expensive process, adding significant cost to the finished weldment. Sometimes it is necessary to grind for fitting purposes or for appearance, but even in these cases it should be minimized if possible.

CAUTION

When using a portable grinder, be sure that it is properly grounded and that the sparks will not fall on others, cause damage, or start a fire. Always maintain control to prevent the stone from catching and gouging the part or yourself.

CAUTION

Be sure that any stone or sandpaper used is rated for a speed in revolutions per minute (RPM) that is equal to or greater than the speed of the grinder itself. Using a stone with a lower-rated RPM can result in its flying apart with an explosive force.

Most grinding is done with a hand angle grinder, **Figure 23-58**. These grinders can be used with a flat or cupped grinding stone or sandpaper. As the grinder is used, the stone will wear down and must be discarded once it has worn down to the paper backing. It is a good practice to hold the grinder at an angle so that if anything is thrown off the stone or metal surface, it will not strike you or others in the area. Because of the speed of the grinding stone, any such impact can cause serious injury.

The grinder must be held securely so that there is a constant pressure on the work. If the pressure is too great, then the grinder motor will overheat and may burn out. If the pressure is too light, then the grinder may bounce, which could crack the grinding stone. Move the grinder in a smooth pattern along the weld. Watch the weld surface as it begins to take the desired shape and change your pattern as needed.

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FIGURE 23-58 Wire brushes and grinding stones used to clean up welds.

Painting and other finishes release fumes such as volatile organic compounds (VOCs), which are often regulated by local, state, and national governments. Special ventilation is required for most paints. Such a ventilation system will remove harmful fumes from the air before it is released back into the environment. Check with your local, state, or national regulating authority before using such products. Read and follow all manufacturer's instructions for the safe use of its product.

CAUTION

Most paints are flammable and must be stored well away from any welding.

Summary

One of the greatest experiences as a welder/fabricator is completing work on a piece of equipment, building, trailer, or other structure. You can proudly point to it and say, "I helped to make that." Learning layout and fabrication techniques will let you someday be able to experience a sense of pride when you are able to say, "I built that all by myself." Welded structures are an enduring monument to your skill as a craftsman, so it is important that every time you build a project, you do it as if it were going to be on display, because it is.

Review

1. List precautions you must take when welding around workers who are not welders.
2. What is a cost advantage of using preformed parts in a fabrication?
3. Why is a prototype custom fabricated before producing multiple weldments?
4. How would a small or tight tolerance affect the layout?
5. How can circles, arcs, and curves be laid out?
6. Which cutting process does not produce a kerf space?
7. What is kerf space?
8. Which of the cutting processes can leave the smallest kerf?
9. What are two common ways to provide for the kerf spacing?
10. What can a template be made of?
11. What is the difference between plate and sheet material?
12. What is a part's tolerance?
13. What can you do to make parts fit without having to recut or regrind them?
14. Why should you avoid recutting or grinding parts whenever possible?
15. What problem can result if the root opening of a weld is too wide?
16. What is the benefit of identifying a single part as the base during assembly?
17. List three types of clamps used to temporarily hold parts in place so that they can be tack welded.
18. What makes some C clamps better for welding than others?
19. What is a simple way of correcting slight alignment problems?
20. What precautions should be taken if a hammer is used to shift a part into alignment?
21. What is the purpose of tack welds?
22. How many tack welds should be used on thin metal compared to thicker metal parts?
23. Does it matter if one of the tack welds breaks during welding? Why?
24. Why is it important not to strike the arc outside of the weld joint?
25. What can happen if a grinding stone with a lower-rated RPM than the grinder is used?

Chapter 24
Welding Codes and Standards

OBJECTIVES

After completing this chapter, the student should be able to

- explain the difference between qualification and certification.
- list the major considerations for selecting a code or standard.
- write a welding procedure and specification.
- identify the three most common codes and describe their major uses.
- outline the steps required to certify a weld and welder.
- explain how a tentative WPS becomes a certified WPS.

KEY TERMS

API Standard 1104

ASME Section IX

AWS D1.1

AWS SENSE (Schools Excelling through National Skills Education)

code

Procedure Qualification Record (PQR)

specification

standard

Welding Procedure Specification (WPS)

Welding Schedule

INTRODUCTION

It is important to know that any weld produced is going to be the best one for the job. A method is also needed to ensure that each weld made in the same plant or on the same type of equipment in another plant will be of the same quality.

To meet these requirements various agencies have established codes and standards. These detailed written outlines explaining exactly how a weld is to be laid out, performed, and tested have made consistent quality welds possible. By having the required information, skilled welders in shops all around the city, state, country, or world can make the same weld to the same level of safety, strength, and reliability.

Welding is one of the very few professions that requires new employees and often current employees to take and pass a skills test to get or keep a job.

Not every product welded needs to be manufactured to the same level. The decision regarding the appropriate code or standard can be one of the most important aspects of welding fabrication. If the wrong one is selected, then the cost of fabrication can be too high or the parts might not stand up to the service.

CODES, STANDARDS, PROCEDURES, AND SPECIFICATIONS

A number of organizations publish codes or specifications that cover a wide variety of welding conditions and applications. The selection of the specific code to be used is made by the engineers, designers, or governmental requirements. Codes and specifications are intended to be guidelines only and must be qualified for specific applications by testing.

A welding **code** or **standard** is a detailed listing of the rules or principles that are to be applied to a specific classification or type of product.

A welding **specification** is a detailed statement of the legal requirements for a specific classification or type of weld to be made on a specific product. Products manufactured to code or specification requirements commonly must be inspected and tested to ensure compliance.

A number of agencies and organizations publish welding codes and specifications. The selection of the particular code or specification to a weldment can be the result of one or more of the following requirements:

- Local, state, or federal government regulations—Many governing agencies require a specific code or standard to be followed.
- Bonding or insuring company—The weld must be shown to be fit for service requirements as established through testing. A bonding or insuring company must feel that the product is the safest that can be produced.
- End user (customer) requirements—The manufacturer considers cost and reliability, that is, as stricter standards are applied to the welding, the cost of the weldments increases. The more lax the standard, the lower the cost, but the reliability and possibly the safety also decrease.
- Standard industrial practices—The code or standard used is considered to be the standard one for the industry and has been in use for some time.

Following are the three most commonly used codes:

- **API Standard 1104**, American Petroleum Institute—Used for pipelines
- **ASME Section IX**, American Society of Mechanical Engineers—Used for pressure vessels and nuclear components
- **AWS D1.1**, American Welding Society—Used for bridges, buildings, and other structural steel
- **AWS SENSE (Schools Excelling through National Skills Education)**—A program that can be used by welding students to demonstrate their skills on a standardized weld test to demonstrate their qualifications.

The following organizations publish welding codes and/or specifications. Most can be contacted for additional information and current price list either directly or through the Internet.

- Association of American Railroads **(AAR)**
- American Association of State Highway and Transportation Officials **(AASHTO)**
- Aerospace Industries Association **(AIA)**
- American Institute of Steel Construction **(AISC)**
- American National Standards Institute **(ANSI)**
- American Petroleum Institute **(API)**
- American Railway Engineering and Maintenance-of-Way Association **(AREMA)**
- American Society of Mechanical Engineers **(ASME)**
- American Welding Society **(AWS)**
- American Water Works Association **(AWWA)**
- Department of Defense Military Specification **(MIL)**
- Society of Automotive Engineers **(SAE)**

WELDING PROCEDURE QUALIFICATION

Welding Procedure Specification (WPS)

A welding procedure specification is a set of written instructions by which a sound weld is made. Normally, the procedure is written in compliance with a specific code, specification, or definition.

Welding Procedure Specification (WPS) is the standard terminology used by the American Welding Society (AWS) and the American Society of Mechanical Engineers (ASME). **Welding Schedule** is the standard federal government, military, or aerospace terminology denoting a WPS. The shortened term ***welding procedures*** is the most common term used by the industry to denote a WPS.

The WPS lists all of the parameters required to produce a sound weld to the specific code, specifications, or definition. Specific parameters such as welding process, technique, electrode or filler, current, amperage, voltage, preheat, and postheat should also be included. The procedure should list a range or set of limitations on each, such as amps (110–150), voltage (17–22), and so on, with the more essential or critical parameters more closely defined or limited.

The WPS should give enough detail and specific information so that any qualified welder could follow it and produce the desired weld. The WPS should always be prepared as a tentative document until it is tested and qualified.

QUALIFYING THE WELDING PROCEDURE SPECIFICATION

The WPS must be qualified to prove or verify that the list of variables—amperage, voltage, filler, and so on—will provide a sound weld. Sample welds are prepared using the

procedure and specifications listed in the tentative WPS. A record of all the parameters used to produce the test welds must be kept. Be sure to record the specifics for the parameters such as voltage, amperage, and so on. This information should be recorded on a form called the **Procedure Qualification Record (PQR)**.

In most cases, the inspection agency, inspector, client, or customer will request a copy of both the WPS and the PQR before allowing production welding to begin.

QUALIFYING AND CERTIFYING

The process of qualifying and then certifying both the WPS and welders requires a number of specific requirements. The requirements may vary from one code or standard to another, but the general process is the same for most. Before you invest in the testing required to qualify and certify processes and welders under a code, you must first obtain a copy of the code you are planning to use. The requirements of codes and standards change from time to time, and it is important that your copy is the most recent version.

The following is a generic schedule of required activities you might follow when qualifying and certifying the welding process, the welder(s), and/or welding operator.

1. A tentative welding procedure is prepared by a person knowledgeable of the process and technique to be used and the code or specification to be satisfied.
2. Test samples are welded in accordance with the tentative WPS, and the welding parameters are recorded on the PQR. The test must be witnessed by an authorized person from an independent testing lab, the customer, an insurance company, or other individual(s) as specified by the code or listing agency.
3. The test samples are tested under the supervision of the same individuals or group that witnessed the test by the applicable requirements, codes, or specifications.
4. If the test samples pass the applicable test, then the procedure has completed qualification. It is then documented as qualified/finalized and is released for use in production.
5. If the test samples do not pass the applicable test, then the tentative WPS value parameters are changed as deemed feasible. Test samples are then rewelded and retested to determine if they do or do not meet applicable requirements. This process is repeated until the test samples pass applicable requirements, and the procedure is finalized and released.
6. The welder making the test samples to be used in qualifying the procedure is normally considered qualified and is then certified in the specific procedure.
7. Other welders to be qualified weld test samples per the WPS, and the samples are tested per applicable requirements. If the samples pass, then the welder is qualified to do the specific procedure and is certified accordingly.
8. A qualified WPS is usable for an indefinite length of time, usually until it is replaced by a process considered more efficient for the product.
9. A welder's certification is normally effective for a period of 6 months unless otherwise specified. However, as long as a welder is routinely producing welds of the same type that the welder has been certified for, the certification is normally extended indefinitely. Even though a welder's certification may still be in effect, they may be periodically asked to recertify.

Figure 24-1 and **Figure 24-2** are two examples of test records used to qualify a WPS and a welder for plate PQR.

GENERAL INFORMATION

Normally, the format of the WPS is not dictated by the code or specification. Any format is acceptable as long as it lists the parameters or variables (essential or nonessential, amps, volts, filler identification, etc.) listed by the code or specification. Most codes or specifications appear in an acceptable or recommended format.

Ideally, the WPS should include all of the information required to make the weld. A welder should be able to be given the WPS without additional instructions and produce the weld. To help with this, it is often a good idea to include supplementary information with each WPS. The information might be basic instructions for the process. With some WPSs you might include several pages as attachments that can give the welder a little review of the setup, operation, testing, inspecting, and so on, which will help to ensure accuracy and uniformity in the welds.

Essential variables are those parameters in which a change is considered to affect the mechanical properties of the weldment to the point of requiring requalification of the procedure. Nonessential variables are those parameters in which a change may be made without requiring requalification of the procedure. However, a change in nonessential variables usually requires a revision to be made.

There are large differences among various codes. The AWS D1.1, ***Structural Welding Code Steel***, allows some prequalified weld joints for specific processes (SMAW, SAW, FCAW, and GMAW). A written procedure is required for these joints, but because the procedure is tentative, it does not require support via a written PQR, **Figure 24-3**.

The Procedure Qualification Requirements regarding positions for groove welds in plate differ among codes. Some codes may require a written procedure for each position. The ASME Section IX, however, qualifies a welder for the 1G position when the welder qualifies for 2G, 3G, or 4G.

WELDING PROCEDURE SPECIFICATION (WPS)

Welding Procedures Specifications No: ____________________ Date: ______________

TITLE:
Welding ____________________ of ____________________ to ____________________

SCOPE:
This procedure is applicable for ____
within the range of ________________________ through ________________________

Welding may be performed in the following positions _______________________________

BASE METAL:
The base metal shall conform to ____

Backing material specification ____

FILLER METAL:
The filler metal shall conform to AWS classification No. _______________________ from AWS specification __________________. This filler metal falls into F-number ____________________ and A-number ____________________.

SHIELDING GAS:
The shielding gas, or gases, shall conform to the following compositions and purity:
____

JOINT DESIGN AND TOLERANCES:

PREPARATION OF BASE METAL:

ELECTRICAL CHARACTERISTICS:
The current shall be ____.

The base metal shall be on the ___________________________________ side of the line.

PREHEAT:

BACKING GAS:

SAFETY:

WELDING TECHNIQUE:

INTERPASS TEMPERATURE:

CLEANING:

INSPECTION:

REPAIR:

SKETCHES:

BEND TEST: Specimen preparation:
Acceptance criteria for bend test:

FIGURE 24-1 Welding Procedure Specification (WPS).

PROCEDURE QUALIFICATION RECORD (PQR)

Welding Qualification Record No: ______(1)______ WPS No: ______(2)______ Date: ______(3)______
Material specification ______(4)______ to ______________
P-No. ______(5)______ to P-No. ______________ Thickness and O.D. ______(6)______
Welding process: Manual ______(7)______ Automatic ______(8)______
Thickness Range ______(9)______

Filler Metal

Specification No. ______(10)______ Classification ______(11)______ F-number ______(12)______
A-number ______(13)______ Filler Metal Size ______(14)______ Trade Name ______(15)______
Describe filler metal (if not covered by AWS specification) ______(16)______
____

Flux or Atmosphere

Shielding Gas ______(17)______ Flow Rate ______(18)______ Purge ______(19)______
Flux Classification ______(20)______ Trade Name ______(21)______

Welding Variables

Joint Type ______(22)______
Backing ______(23)______
Passes and Size ______(24)______
No. of Arcs ______(25)______
Ampere ______(26)______
Travel Speed ______(27)______
Position ______(29)______
Preheat ______(30)______
Bead Type ______(31)______
Current ______(32)______
Volts ______(33)______
Oscillation ______(34)______
Interpass Temperature Range ______(28)______

Weld Results

Appearance ______(35)______ Weld Size ______(36)______

Guided-Bend Test

Type	Result	Type	Result
(37)	(38)		

Tensile Test

Specimen No.	Dimensions Width | Thickness	Area	Ultimate Total Load, lb.	Ultimate Unit Stress, psi	Character of Failure and Location
(39)	(40)	(41)	(42)	(43)	(44)

Welder's Name ______(45)______ Identification No. ______(46)______ Laboratory Test No. ______________
By virtue of these test welder meets performance requirements.
Test Conducted by ______(47)______ Address ______________
per ______(48)______ Date ______(49)______
We certify that the statements in this record are correct and that the test welds performed and tested are in accordance with the WPS.

Manufacture ______(50)______
Signed by ______________
Date ______________

FIGURE 24-2 Procedure Qualification Record (PQR).

WELDING PROCEDURE SPECIFICATION (WPS)
FOR
ABC, INC.

Welding Procedures Specifications No: WPS-1A Date: 8-8-15

TITLE:
Welding GTAW of 3" SCHEDULE 80 316 SEAMLESS PIPE to 3" SCHEDULE 80 316 PIPE.

SCOPE:
This procedure is applicable for V-GROOVED WELDS IN PIPING within the range of 3" SCHEDULE 80 through 3" SCHEDULE 80.
Welding may be performed in the following positions 1G.

BASE METAL:
The base metal shall conform to ASTM A376 GRADE TP-316 SEAMLESS PIPE SCHEDULE 80 P8.
Backing material specification: N/A.

FILLER METAL:
The filler metal shall conform to AWS classification No. ER 316L from AWS specification A5.9. This filler metal falls into F-number 6 and A-number 8.

SHIELDING GAS:
The shielding gas, or gases, shall conform to the following compositions and purity:
WELDING GRADE ARGON.

JOINT DESIGN AND TOLERANCES:

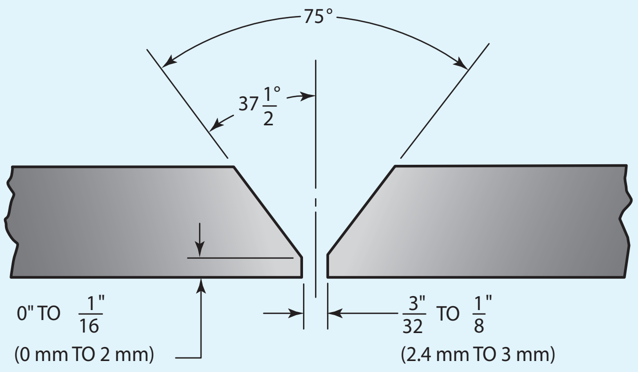


FIGURE 1

PREPARATION OF BASE METAL:
The edges of parts to be joined shall be prepared by machining. All parts to be joined must be cleaned prior to welding of all hydrocarbons and other contaminants, such as cutting fluids, grease, oil, and primers, by suitable solvents. Both the inside and outside surfaces within 2" of the joint must be mechanically cleaned by using a stainless steel wire brush that has not been used for other purposes or pickled with 10% to 20% nitric acid solution. Joint alignment shall be maintained by four (4) tack welds equally spaced around the joint. The tack welds are to be made using the same GTA welding process used for the root pass. Both ends of each tack weld are to be ground to a taper prior to the beginning of the root pass.

FIGURE 24-3 Welding Procedure Specification (WPS). (*Continued*)

ELECTRICAL CHARACTERISTICS:

The current shall be DIRECT CURRENT ELECTRODE NEGATIVE .

The base metal shall be on the POSITIVE side of the line.

PREHEAT:

The parts shall not be welded if they are below 70°F.

BACKING GAS:

To protect the inside of the root surface from the formation of oxides during welding, a continuous flow of argon into the part is required. The open end of the part must be capped (Figure 1) and the unwelded joint must be taped prior to the beginning of any welding. The backing gas must have a flow rate of 10 CFH to 15 CFH, and the flow must begin 2 minutes before welding starts and continue until the part has cooled to room temperature. The backing gas may be stopped between welds only if the part is allowed to cool to room temperature.

WELDING TECHNIQUE:

The GTA welding process is to be used for making the weld.

Electrode	1/8-inch diameter EWTh-2
Electrode tip geometry	Tapered 2 to 3 times length to diameter
Nozzle	1/2 inch diameter
Shielding gas	Argon
Shielding gas flow rate	20 CFH to 45 CFH
Current, A	90 to 150
Polarity	DCEN
Arc voltage, V	12 to 15
Filler metal type	ER 316L
Filler metal size	3/32 inch to 1/8 inch diameter
Backing gas	Argon
Backing gas flow rate	10 to 15 CFH
Preheat	70 degrees min.
Interpass temp.	500 degrees max.
Travel speed	As required

TACK WELDS:

With the pipe securely clamped into welding jig and the flange fitting properly located with the correct root gap, the four tack welds are to be performed (Figure 2). Holding the electrode so that it is very close to the root face but not touching (Figure 3), slowly increase the current until the arc starts and a molten weld pool is formed. Adding filler metal to maintain a slight convex weld face and a flat or slightly concave root face (Figure 4). When it is time to end the tack weld, lower the current slowly so that the molten weld pool can be tapered down in size (Figure 5). When all four tack welds are complete, allow the pipe to cool. Using a grinding wheel that has never been used on any metal other than 316 stainless steel, feather the ends of the tack welds.

FIGURE 24-3 Welding Procedure Specification (WPS). (*Continued*)

ROOT WELD:
Holding the electrode so that it is very close to the root face but not touching, slowly increase the current until the arc starts and a molten weld pool is formed. As the weld progresses, add filler metal as required to maintain a slightly concave root face. When it is necessary to stop the weld, to reposition the part, or the weld is completed, the current must be lowered slowly so that the molten weld pool can be tapered down in size.

FILLER AND COVER WELDS:
Position the pipe so that the weld is in the 1G position. Connect the purge gas and start the flow 2 minutes before welding begins. A 5 CFH flow must be maintained during the remainder of the welding. The backing gas may be stopped if welding is to be discontinued for more than 15 minutes. A slightly higher welding current level will be required for the remaining welds. Start each of the filler welds so that the starting and ending points will be staggered (Figure 6). The size of each of the filler passes and the cover passes must not be larger than 1/4 inch wide. The weld bead size must be small so as to minimize the heat input in the weld joint and so as to allow the weld to stress relieve itself. The finished weld contour must be within tolerance (Figure 7).

INSPECTION:
The weld is to be inspected visually in accordance to AWS B1, Guide for Nondestructive Inspection of Welds. It must be found to be within tolerance as stated herein.

REPAIR:
Only slight surface discontinuities may be repaired with the approval of the QC department.

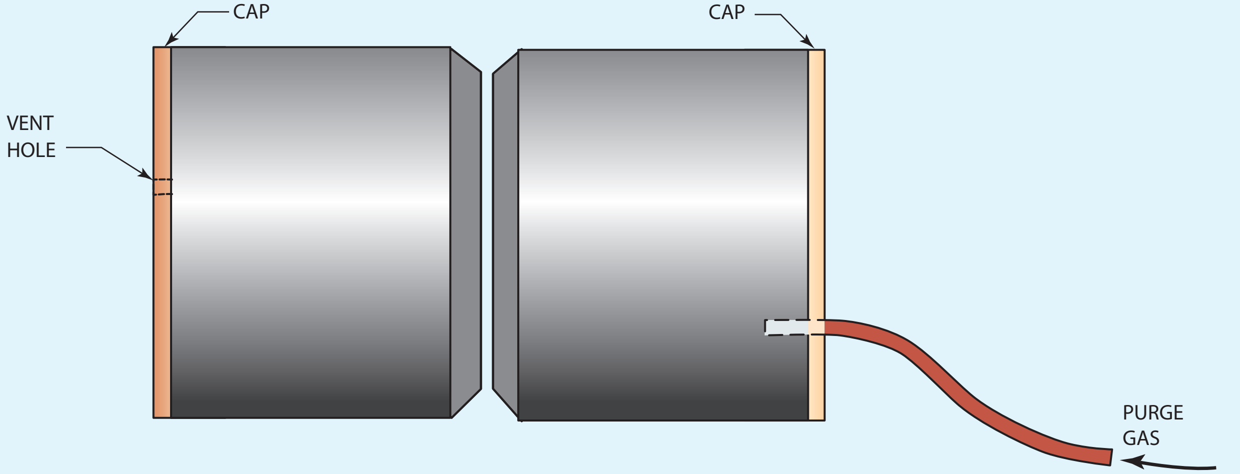


FIGURE 2

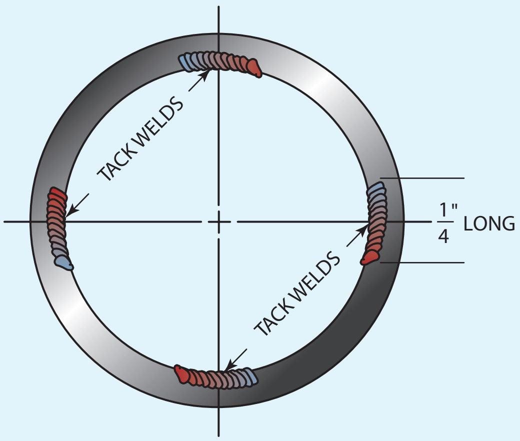


FIGURE 3

FIGURE 24-3 Welding Procedure Specification (WPS). (*Continued*)

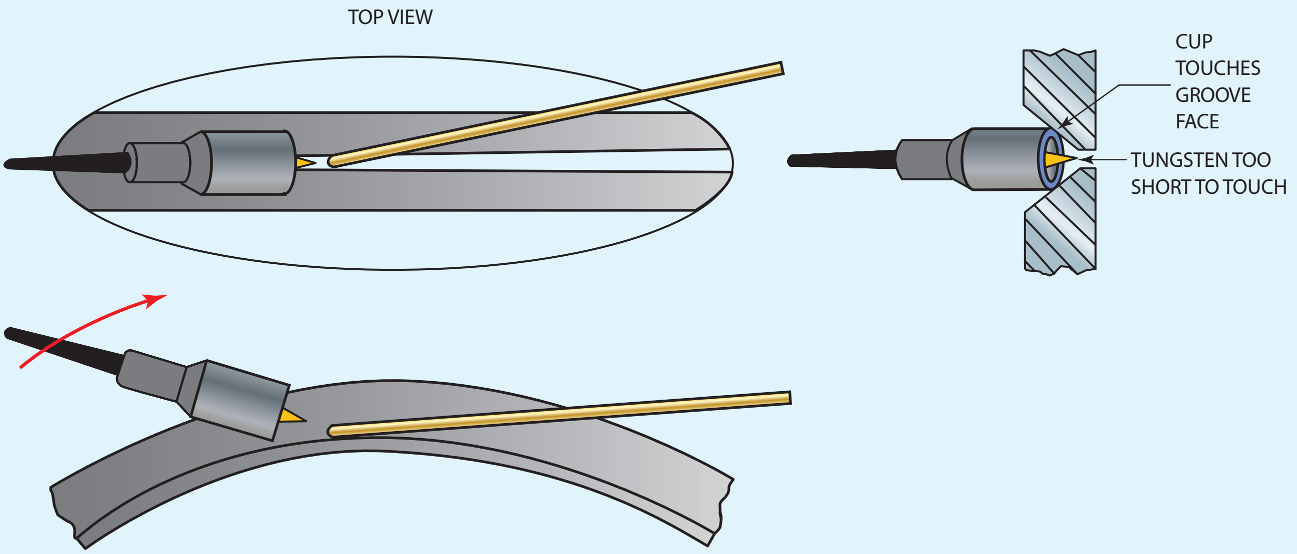


FIGURE 4

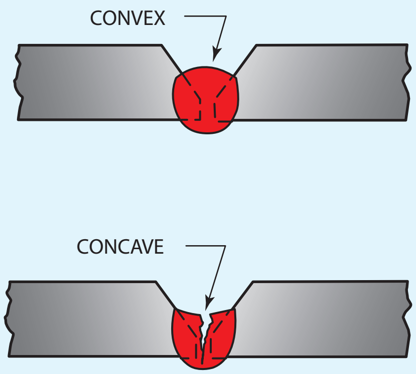


FIGURE 5

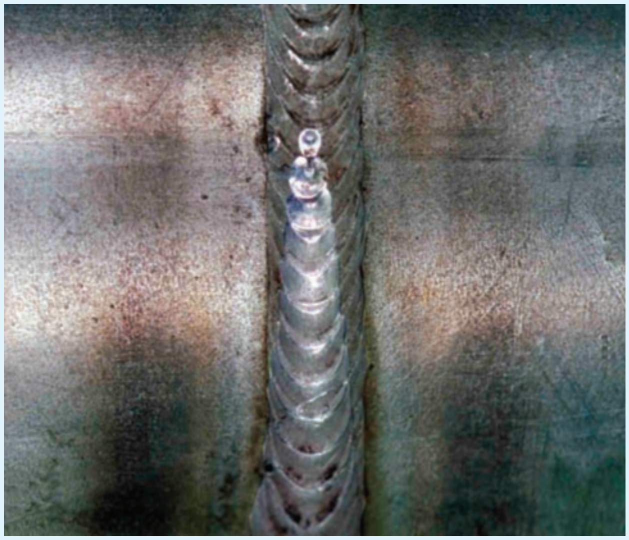


FIGURE 6

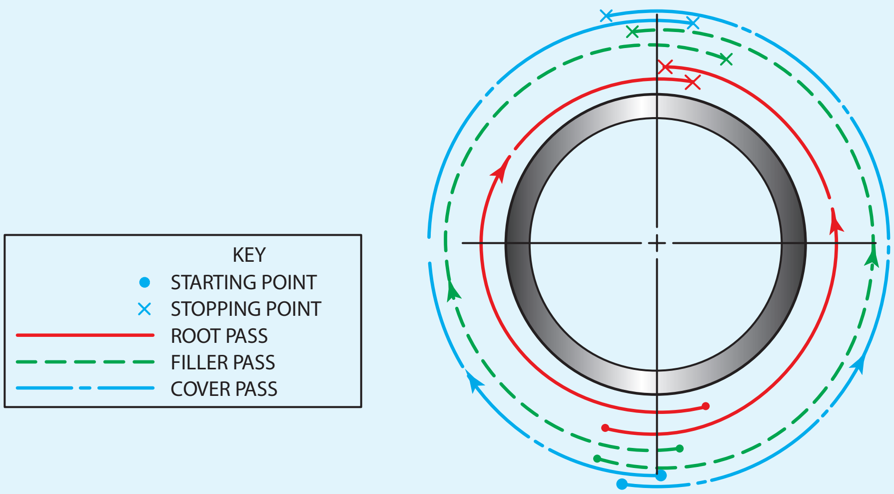


FIGURE 7

FIGURE 24-3 Welding Procedure Specification (WPS). (*Continued*)

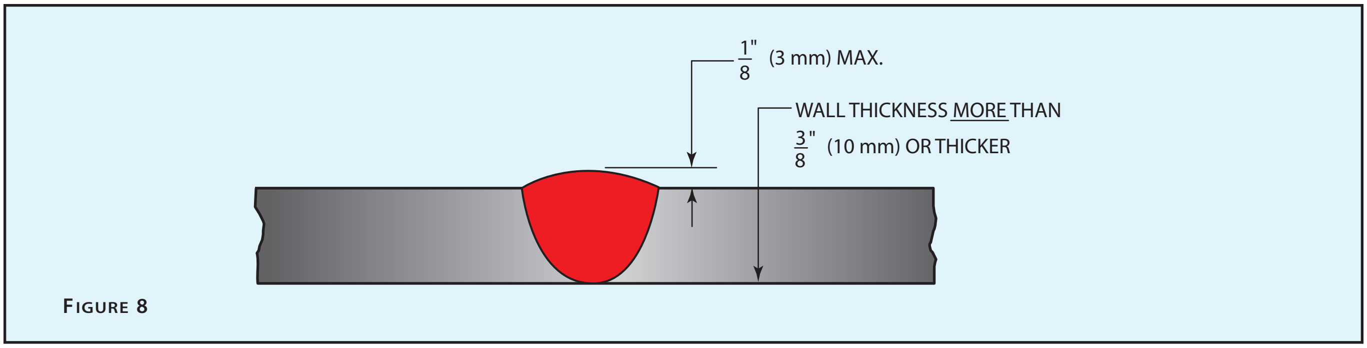


FIGURE 24-3 Welding Procedure Specification (WPS). (*Concluded*)

Ordinarily, the welder must be qualified/certified in accordance with a specific WPS. The welder's qualifying test plate may be examined radiographically or ultrasonically in place of bend tests. Specific codes or specifications must be referenced for details of the number of actual tensile, bend, or other type of test specimens and tests to be performed. For example, AWS D1.1 and ASME Section IX do not require a "Nick-Break Test Specimen," but API Standard 1104 does require it.

PRACTICE 24-1

Writing a Welding Procedure Specification (WPS)

Using the form provided and following the example, Figure 24-3, you will write a welding procedure specification. **Figure 24-4** is a form that is a composite of sample WPS forms provided by AWS, ASME, and API codes. You may want to obtain a copy of one of the codes or standards and compare a weld you made to the standard. Most of the unique information is provided in this short outline. Additional information that may be required for this form can be found in figures in this chapter. You may need to refer to some of the chapters on welding or to your notes to establish the actual limits of the welding variables (voltage, amperage, gas flow rates, nozzle size, etc.).

NOTE

Not all of the blanks will be filled in on the forms. The forms are designed to be used with a large variety of weld procedures, so they have spaces that will not be used each time.

1. The WPS number is usually made up following a system established by the company. This number may or may not include coded information relating to the date it was written, who wrote it, material or process data, and so on.
2. Date that the WPS was written or effective.
3. The welding process(es) that will be used to perform the weld, such as SMAW, GMAW, GTAW, and so on.
4. The actual material type and thickness or pipe type and diameter and/or wall thickness. If all the material or pipe being joined is the same, then the same information will appear before and after "to."
5. Fillet or groove weld and the joint type, such as butt, lap, tee, and so on.
6. Thickness range qualified or diameter range qualified. For both plate and pipe, a weld performed successfully on one thickness qualifies a welder to weld on material within that range. See **Table 24-1** for a list of thickness ranges.
7. Material position: 1G, 2G, 3G, 4G, 1F, 2F, 3F, 4F, 5G, 6G, 6GR, Figure 24-3.
8. Base metal specification: This is the ASTM specification for the type and grade of material, including the P-number, **Table 24-2**.
9. If a backing material is used, then its ASTM or other specification information must be included here.
10. Classification number: This is the standard number found on the electrode or electrode box, such as E6010, E7018, E316-15, ER70S-3, or E70T-1.
11. Filler metal specification number: The AWS has specifications for chemical composition and physical properties for electrodes. Some of these specifications are listed in **Table 24-3**.
12. F-number: This is a specific grouping number for several classifications of electrodes having similar composition and welding characteristics. **Table 24-4** lists the F-number corresponding to the electrode used.
13. A-number: This is the classification of weld metal analysis. **Table 24-5** lists the A-numbers.
14. Shielding gas(es) and flow rate for GMAW, FCAW, or GTAW.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

WELDING PROCEDURE SPECIFICATION (WPS)

Welding Procedures Specifications No: ___(1)___ Date: ___(2)___

TITLE:
Welding ___(3)___ of ___(4)___ to ___(4)___.

SCOPE:
This procedure is applicable for ___(5)___
within the range of ___(6)___ through ___(6)___.

Welding may be performed in the following positions ___(7)___.

BASE METAL:
The base metal shall conform to ___(8)___.

Backing material specification ___(9)___.

FILLER METAL:
The filler metal shall conform to AWS classification No. ___(10)___ from AWS specification ___(11)___. This filler metal falls into F-number ___(12)___ and A-number ___(13)___.

SHIELDING GAS:
The shielding gas, or gases, shall conform to the following compositions and purity:
___(14)___

JOINT DESIGN AND TOLERANCES: (15)

PREPARATION OF BASE METAL: (16)

ELECTRICAL CHARACTERISTICS:
The current shall be ___(17)___.

The base metal shall be on the ___(18)___ side of the line.

PREHEAT: (19)

BACKING GAS: (20)

WELDING TECHNIQUE: (21)

INTERPASS TEMPERATURE: (22)

CLEANING: (23)

INSPECTION: (24)

REPAIR: (25)

SKETCHES: (26)

FIGURE 24-4 Welding Procedure Specification (WPS).

Plate Thickness (T) Tested in. (mm)	Plate Thickness (T) Qualified in. (mm)	
1/8 ≥ T ≤ 3/8* (3.1 ≥ T ≤ 9.5)	1/8 to 2T (3.1 to 2T)	
3/8 (9.5)	3/4 (19.0)	
3/8 ≥ T ≤ 1 (9.5 ≥ T ≤ 25.4)	2T 2T	
1 and over (25.4 and over)	Unlimited Unlimited	
Pipe Size of Sample Weld		
Diameter in. (mm)	**Wall Thickness, T**	
2 (50.8)	Sch. 80	
or		
3 (76.2)	Sch. 40	
6 (152.4)	Sch. 120	
or		
8 (203.2)	Sch. 80	
Pipe Size Qualified		
Diameter in. (mm)	**Wall Thickness in. (mm)**	
3/4 (19.0)	Minimum	Maximum
through	0.063 (1.6)	0.674 (17.1)
4 (101.6)		
4 (101.6)	0.187 (4.7)	Any
and over		

*Thickness (T) is equal to or greater than 1/8 in. (≥) and thickness (T) is equal to or less than 3/8 in. (≤).

TABLE 24-1 Test Specimens and Range of Thickness Qualified

PRACTICE 24-2

Procedure Qualification Record (PQR)

Following the procedure you wrote in Practice 24-1, you are going to make the weld to see if your tentative welding procedure and specification can be certified. Complete a copy of the form provided to record all of the appropriate information, Figure 24-2.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor.

1. The PQR number is usually made up following a system established by the company. This number may or may not include coded information relating to the product being welded, material or process data, and the like.

	Type of Material
P-1	Carbon steel
P-3	Low-alloy steel
P-4	Low-alloy steel
P-5	Alloy steel
P-6	High-alloy steel—predominantly martensitic
P-7	High-alloy steel—predominantly ferritic
P-8	High-alloy steel—austenitic
P-9	Nickel alloy steel
P-10	Specialty high-alloy steels
P-21	Aluminum and aluminum-base alloys
P-31	Copper and copper alloy
P-41	Nickel

TABLE 24-2 P-Numbers

	Filler Metal Type
A5.10	Aluminum and Aluminum-Alloy Wire Electrodes and Rods
A5.3	Aluminum and Aluminum-Alloy SMAW Electrodes
A5.8	Brazing and Braze Welding Filler Metal
A5.1	Carbon Steel SMAW Electrodes
A5.20	Carbon Steel FCAW Electrodes
A5.17	Carbon Steel SAW Wires and Fluxes
A5.18	Carbon Steel GMAW Electrodes and Rods
A5.2	Carbon and Low-Alloy Steel Rods for OFW
A5.5	Alloy Steel for SMAW
A5.23	Low-Alloy Steel Electrodes and Fluxes for SAW
A5.28	Low-alloy Steel Electrods and Rods for GMAW
A5.29	Low-alloy Steel for FCAW

TABLE 24-3 Specification Numbers

Group Designation	Metal Types	AWS Electrode Classification
F1	Carbon steel	EXX20, EXX24, EXX27, EXX28
F2	Carbon steel	EXX12, EXX13, EXX14
F3	Carbon steel	EXX10, EXX11
F4	Carbon steel	EXX15, EXX16, EXX18
F5	Stainless steel	EXXX15, EXXX16
F6	Stainless steel	ERXXX
F22	Aluminum	ERXXXX

TABLE 24-4 F-Numbers

2. The WPS number on which the PQR is based.
3. The date on which the welding took place.
4. Base metal specification: This is the ASTM specification for the type and grade of material.
5. Table 24-2 lists some commonly used metals and their P-numbers.
6. For flat material testing—material thickness. For pipe testing—outside diameter (OD) and wall thickness.
7. Manual welding processes are used to qualify a welder. Specify the process, such as GMAW, FCAW, SMAW, GTAW, and so on.
8. Automatic welding processes are used to qualify a welding operator. Specify the process (SAW, ESW, etc.).
9. Thickness range qualified (or) diameter range qualified. For both plate and pipe, a weld performed successfully on one thickness qualifies a welder to weld on material within that range. See Table 24-1 for a list of thickness ranges.
10. Filler metal specification number: The AWS has specifications for chemical composition and physical properties for electrodes. Some of these specifications are listed in Table 24-3.
11. Classification number: This is the standard number found on the electrode or electrode box, such as E6010, E7018, E316-15, or ER1100.
12. F-number: This is a specific grouping number for several classifications of electrodes having similar composition and welding characteristics. See Table 24-4 for the F-number corresponding to the electrode used.
13. A-number: This is the classification of weld metal analysis. See Table 24-5 for a list of A-numbers.
14. Give the diameter of electrode used.
15. Give the manufacturer's identification name or number.

		Analysis					
A No.	Types of Weld Deposit	C %	Mn %	Si %	Mo %	Cr %	Ni %
1	Mild steel	0.15	1.6	1.0	—	—	—
2	Carbon-moly	0.15	1.6	1.0	0.4 – 0.65	0.5	—
3	Chrome (0.4% to 2%)-moly	0.15	1.6	1.0	0.4 – 0.65	0.4 – 2.0	—
4	Chrome (2% to 6%)-moly	0.15	1.6	2.0	0.4 – 1.5	2.0 – 6.0	—
5	Chrome (6% to 10.5%)-moly	0.15	1.2	2.0	0.4 – 1.5	6.0 – 10.5	—
6	Chrome-martensitic	0.15	2.0	1.0	0.7	11.0 – 15.0	—
7	Chrome-ferritic	0.15	1.0	3.0	1.0	11.0 – 30.0	—
8	Chromium-nickel	0.15	2.5	1.0	4.0	14.5 – 30.0	7.5 – 15.0
9	Chromium-nickel	0.30	2.5	1.0	4.0	25.0 – 30.0	15.0 – 37.0
10	Nickel to 4%	0.15	1.7	1.0	0.55	—	0.8 – 4.0
11	Manganese-moly	0.17	1.25 – 2.25	1.0	0.25 – 0.75	—	0.85
12	Nickel-chrome-moly	0.15	0.75 – 2.25	1.0	0.25 – 0.8	1.5	1.25 – 2.25

TABLE 24-5 A-Number Classification of Ferrous Metals

16. List the manufacturer's chemical composition and physical properties as provided if the filler metal is not covered by an AWS specification.
17. Shielding gas or gas mixture for GMAW, FCAW, or GTAW.
18. Flow rate in cubic feet per hour (cfh).
19. The amount of time that the shielding gas is to flow to purge air from the welding zone.
20. SAW flux classification.
21. The manufacturer's identification name or number for the SAW flux.
22. Butt, lap, tee, or other joint type.
23. Backing strip material specification. This is the ASTM specification number.
24. The number of passes and the size.
25. Usually one, except for some automatic SAW processes that may use multiple electrodes with multiple arcs.
26. The amount of current in amps used to make the weld. If the machine being used for the weld does not have an amp meter, then a meter must be attached to the welding lead, within 2 ft (1.5 m) of the electrode holder, to get this reading.
27. The travel speed in inches per minute is usually given for machine or automatic welds.
28. This is the maximum temperature that the base metal is allowed to reach during the weld. Welding must stop and the part allowed to cool if this temperature is reached.
29. Test position: 1G, 2G, 3G, 4G, 1F, 2F, 3F, 4F, 5G, 6G, 6GR, **Figure 24-5**.
30. This is the minimum temperature that the base metal must be before welding can start.
31. Groove or fillet weld.
32. AC, DCEP, or DCEN.
33. The voltage is included for all welding processes.
34. The type of electrode movement used when making the weld.
35. Visually inspect the weld and record any flaws.
36. Record the legs and reinforcement dimensions. Measure and record the depth of the root penetration.
37. Four (4) test specimens are used for 3/8-in. (10-mm) or thinner metal. Two (2) will be root bent and two (2) will be face bent. For thicker metal all four (4) will be side bent.
38. Visually inspect the specimens after testing and record any discontinuities.
39. Identification number that was marked on the specimen.
40. Width and thickness of test section of the specimen.
41. Cross-sectional area of specimen in the test area.
42. The load at which the specimen failed.
43. The maximum load divided by the specimen's original area converts the ultimate total load for the specimen to the pounds per square inch (psi) that was required to break the material.
44. The type of failure, whether it was ductile or brittle, and where the failure occurred relative to the weld.
45. Welder's name: This is the person who performed the weld.
46. Identification number: On a welding job, every person has an identification number that is used on the time card and paycheck. In this space, you can write the class number or section number because you do not have a clock number.
47. The name of the person who interpreted the results.
48. Qualifications of the test interpreter: This is usually a Certified Welding Inspector or other qualified person.
49. Date the results of the test were completed.
50. The name of the company that requested the test. ◆

Summary

Over the years, often through trial and error, welders and welding engineers have developed standards, codes, and specifications that, when followed, will produce welds that will be sound and provide years of service. It is important to know that, under such codes and standards, not all welds must be perfect. Some levels of imperfection are acceptable and, through years of experience, such minor flaws have been determined to not be critical or to result in structural failure.

Being able to follow such codes and standards is important in that it helps control welding costs. The more precise the weld produced, the more expensive the weld is to produce. As a welder attempts perfection, welding preparation time, welding time, postweld cleanup time, and unnecessary rewelding time all increase, thus increasing the cost of the weld. Knowing what is "fit for service" as set by the code or standard is essential. Likewise, failing to produce a weld to the required code or standard can cause structural failure. Therefore, it is important that you familiarize yourself with the standards for your company's requirements.

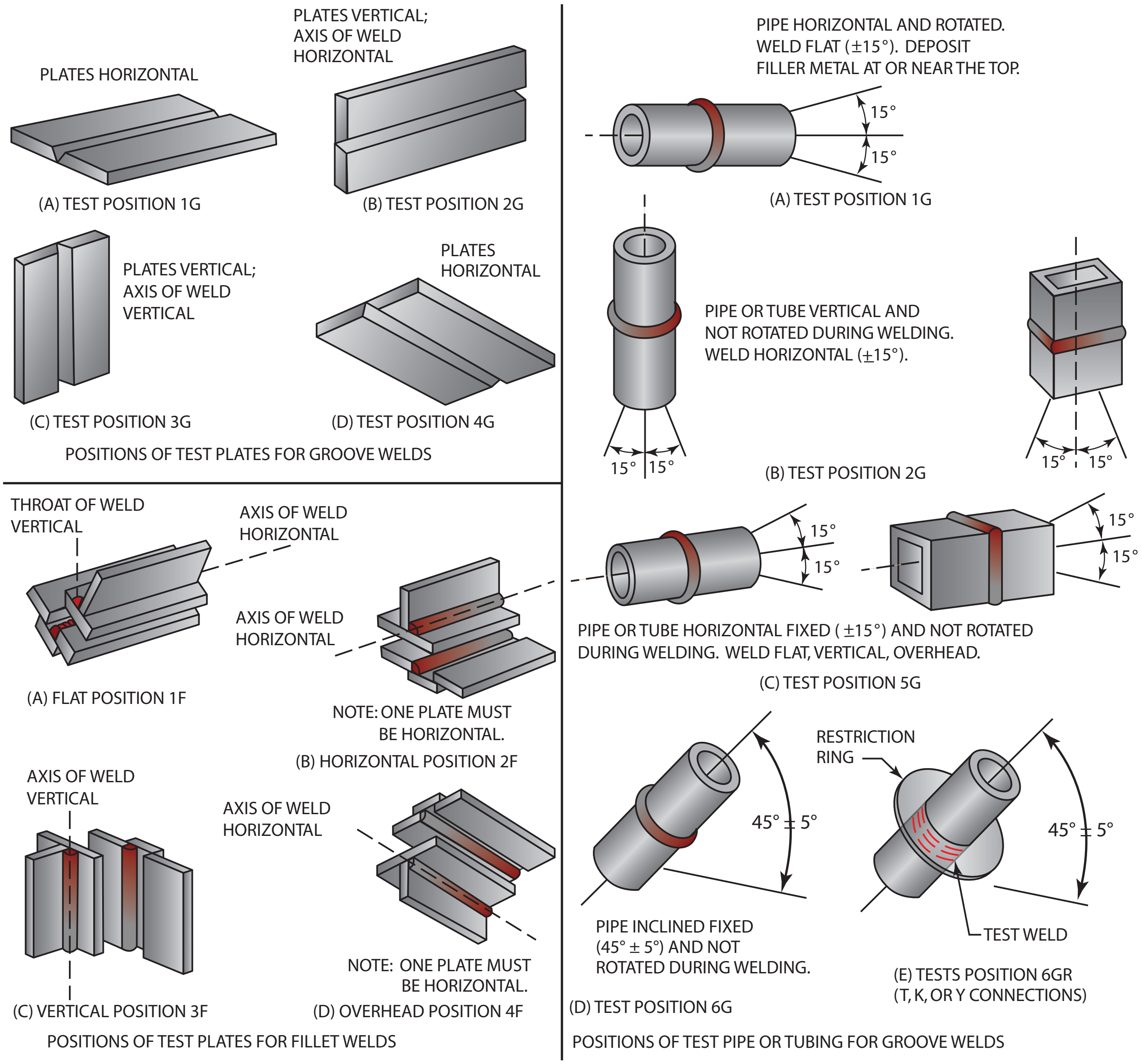


FIGURE 24-5 Weld positions.

Review

1. Why is it important to select the correct welding code or standard?
2. What are codes and standards?
3. What is the difference between welding codes or standards and welding specifications?
4. What might influence the selection of a particular code or specification for welding?
5. As stricter standards are applied to the welding process, what happens to the cost of the weldment?
6. What can happen if welding standards are lax?
7. What are three commonly used codes?
8. What is a WPS?
9. What information should be included in a WPS?
10. What is the form called that records the parameters used to produce a test weld?
11. Who should witness the test welding being performed for a tentative WPS?

Chapter 25

Testing and Inspection

OBJECTIVES

After completing this chapter, the student should be able to

- describe the difference between mechanical or destructive and nondestructive testing.
- list the 12 most common discontinuities and the nondestructive methods of locating them.
- discuss how both mechanical or destructive and nondestructive testing are performed.
- explain why welds are tested.
- evaluate a weld according to a given standard or code.

KEY TERMS

Brinell hardness tester

defect

discontinuities

eddy current inspection (ET)

etching

mechanical testing (DT)

nondestructive testing (NDT)

quality control

radiographic inspection (RT)

Rockwell hardness tester

shearing strength

tolerance

ultrasonic inspection (UT)

INTRODUCTION

It is important to know that a weld will meet the requirements of the company and/or codes or standards. It is also necessary to ensure the quality, reliability, and strength of a weldment. To meet these demands, an active inspection program is needed. The extent to which a welder and product are subjected to testing and inspection depends on the intended service of the product. Items that are to be used in light, routine-type service, such as ornamental iron, fence posts, gates, and so forth, are not inspected as critically as products in critical use. Some of the items in critical use include a main nuclear reactor containment vessel, oil refinery high-pressure vessels, aircraft airframes, bridges, and so on. The type of inspection required is then very much dependent on the type of service that the welded part will be required to withstand. The quality of the weld that will pass or be acceptable for one welding application may not meet the needs of another.

The basis for the types of inspection and the criteria for acceptance are all based on internationally accepted codes and standards. A number of different agencies have established these codes and standards, most of which are based on the type of industries that the welds on a fabrication are destined to be used in. For example, there are codes and standards for bridges, piping systems, buildings, shipping, and many others.

NOTE

As a testament to the value of codes and the importance of inspections, following the terrorist attack on the World Trade Center towers, an extensive study of the welds was undertaken. Despite the horrendous collapse of the two towers, the investigators could not find any welds that had failed.

American Bureau of Shipping
American Petroleum Institute
American Society of Mechanical Engineers
American Society for Testing and Materials
American Welding Society
British Welding Institute
United States government

*A more complete listing of agencies with addresses is included in the Appendix IX.

TABLE 25-1 Major Code Issuing Agencies*

QUALITY CONTROL (QC)

Once a code or standard has been selected, a method is chosen for ensuring that the product meets the specifications. The two classifications of methods used in product **quality control** are destructive or mechanical testing and nondestructive testing. These methods can be used individually, or a combination of the two methods can be used. **Mechanical testing (DT)** methods, except for hydrostatic testing, result in the product being destroyed. **Nondestructive testing (NDT)** does not destroy the part being tested.

Mechanical testing is commonly used to qualify welders or welding procedures. It can be used in a random sample testing procedure in mass production. In many cases, a large number of identical parts are made, and a chosen number are destroyed by mechanical testing. The results of such tests are valid only for welds made under the same conditions because the only weld strengths known are the ones resulting from the tested pieces. It is then assumed that the strengths of the nontested pieces are the same.

Nondestructive testing is used for welder qualification, welding procedure qualification, and product quality control. Because the weldment is not damaged, all the welds can be tested and the part can actually be used for its intended purpose. Because the parts are not destroyed, more than one testing method can be used on the same part. Frequently, only part of the welds is tested to save time and money. The same comparison of random sampling applies to these tests as it does for mechanical testing. Critical parts or welds are usually 100% tested.

DISCONTINUITIES AND DEFECTS

Discontinuities and flaws are interruptions in the typical structure of a weld. They may be a lack of uniformity in the mechanical, metallurgical, or physical characteristics of the material or weld. All welds have discontinuities and flaws, but they are not necessarily defects.

A **defect**, according to AWS, is "a discontinuity or discontinuities that by nature or accumulated effect render a part or product unable to meet minimum applicable acceptance standards or specifications. The term designates rejectability."

In other words, many acceptable products may have welds that contain discontinuities. But no products may have welds that contain defects. The only difference between a discontinuity and a defect is when the discontinuity becomes so large or when there are so many small discontinuities that the weld is not acceptable under the standards for the code for that product. Some codes are more strict than others, so the same weld might be acceptable under one code but not under another.

Ideally, a weld should not have any discontinuities, but that is practically impossible. The difference between what is acceptable, fit for service, and perfection is known as **tolerance**. In many industries, the tolerances for welds have been established and are available as codes or standards. **Table 25-1** lists a few of the agencies that issue codes or standards. Each code or standard gives the tolerance that changes a discontinuity to a defect.

When evaluating a weld, it is important to note the type of discontinuity, the size of the discontinuity, and the location of the discontinuity. Any one of these factors or all three can be the deciding factors that, based on the applicable code or standard, change a discontinuity to a defect.

The 12 most common discontinuities are as follows:

- Porosity
- Inclusions
- Inadequate joint penetration
- Incomplete fusion
- Arc strikes
- Overlap (cold lap)
- Undercut
- Cracks
- Underfill
- Laminations
- Delaminations
- Lamellar tears

Some welding processes are more likely than others to cause some of the discontinuities. For example, laser welding would never produce an arc strike discontinuity and resistance spot welding could never produce a weld with underfill. **Table 25-2** lists the common discontinuities and the welding processes that might cause each.

Porosity

Porosity results when gas that was dissolved in the molten weld pool forms bubbles that are trapped as the metal cools

	Shielded Metal Arc Welding (SMAW)	Gas metal Arc Welding (GMAW)	Flux cored Arc Welding (FCAW)	Gas Tungsten Arc Welding (GTAW)	Oxyacetylene Welding (OAW)	Oxyhydrogen Welding (OHW)	Submerged Arc Welding (SAW)	Laser Bam Welding (LBW)	Plasma Arc Welding (PAW)	Electron Beam Welding (EBW)	Carbon Arc Welding (CAW)	Pressure Gas Welding (PGW)	Electroslag Welding (ESW)	Thermite Welding (TW)
Porosity	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Inclusions	X	X	X				X				X		X	X
Inadequate joint penetration	X	X	X		X		X		X	X	X		X	
Incomplete fusion	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Arc strikes	X	X	X	X										
Overlap (cold lap)	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Undercut	X	X	X	X	X	X	X		X		X			
Crater cracks	X	X	X	X	X	X	X		X		X			
Underfill	X	X	X	X	X	X	X		X		X			

TABLE 25-2 Common Discontinuities and the Joint Types They Might be Found On

to become solid. The bubbles that make up porosity form within the weld metal; for that reason, they cannot be seen as they form. These gas pockets form in the same way that bubbles form in a carbonated drink as it warms up or as air dissolved in water forms bubbles in the center of a cube of ice. Porosity appears in either spherical (ball-shaped) or cylindrical (tube- or tunnel-shaped) form. Cylindrical porosity is called wormhole. The rounded edges tend to reduce the stresses around them. Therefore, unless porosity is extensive, there is little or no loss in strength.

Porosity is most often caused by improper welding techniques, contamination, or an improper chemical balance between the filler and base metals.

Improper welding techniques may result in shielding gas not properly protecting the molten weld pool. For example, the E7018 electrode should not be weaved wider than two and one-half times the electrode diameter because very little shielding gas is produced. As a result, parts of the weld are unprotected. Nitrogen from the air that dissolves in the weld pool and then becomes trapped during escape can produce porosity.

The intense heat of the weld can decompose paint, dirt, or oil from machining and rust or other oxides, producing hydrogen. This gas, like nitrogen, can also become trapped in the solidifying weld pool, producing porosity. When it causes porosity, hydrogen can also diffuse into the heat-affected zone, producing underbead cracking in some steels. The level needed to crack welds is below that necessary to produce porosity.

Porosity can be grouped into the following four major types:

- Uniformly scattered porosity is most frequently caused by poor welding techniques or faulty materials, **Figure 25-1**.

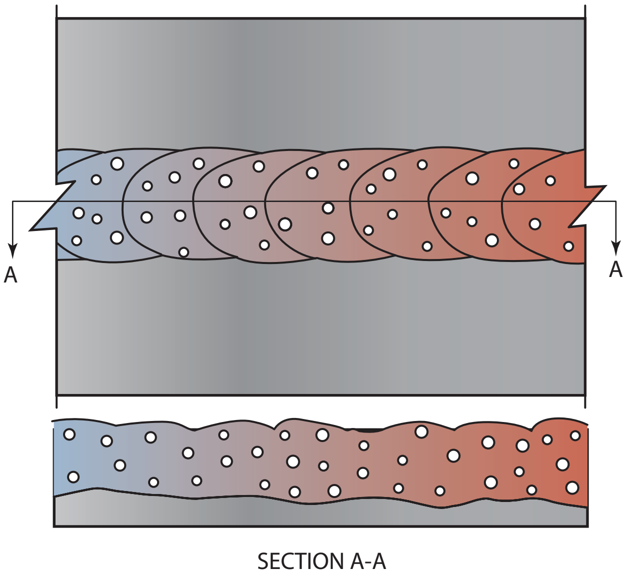


FIGURE 25-1 Uniformly scattered porosities.

- Clustered porosity is most often caused by improper starting and stopping techniques, **Figure 25-2**.
- Linear porosity is most frequently caused by contamination within the joint, root, or interbead boundaries, **Figure 25-3**.
- Piping porosity, or wormhole, is most often caused by contamination at the root, **Figure 25-4**. This porosity is unique because its formation depends on the gas escaping from the weld pool at the same rate as the pool is solidifying.

Refer to Table 25-2 for a listing of welds that may produce porosity.

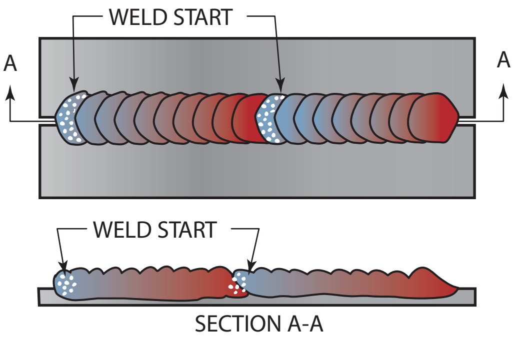


FIGURE 25-2 Clustered porosity.

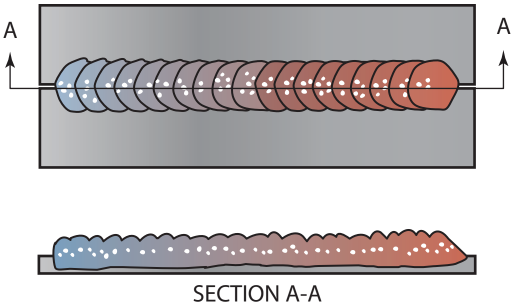


FIGURE 25-3 Linear porosity.

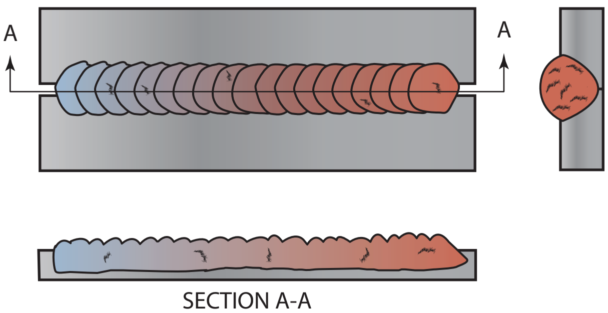


FIGURE 25-4 Piping or wormhole porosity.

Inclusions

Inclusions are nonmetallic materials, such as slag and oxides, that are trapped in the weld metal, between weld beads, or between the weld and the base metal. Inclusions sometimes are jagged and irregularly shaped. Also, they can form in a continuous line. This causes stresses to concentrate and reduces the structural integrity (loss in strength) of the weld.

Although not visible, their development can be expected if prior welds were improperly cleaned or had a poor contour. Unless care is taken in reading radiographs, the presence of slag inclusions can be interpreted as other defects.

Linear slag inclusions in radiographs generally contain shadow details; otherwise, they could be interpreted as lack-of-fusion defects. These inclusions result from a lack of slag control caused by poor manipulation that allows the slag to flow ahead of the arc, by not removing all the slag from previous welds, or by welding highly crowned, incompletely fused welds.

Scattered inclusions can resemble porosity but, unlike porosity, they are generally not spherical. These inclusions can also result from inadequate removal of earlier slag deposits and poor manipulation of the arc. Additionally, heavy mill scale or rust serves as their source, or they can result from unfused pieces of damaged electrode coatings falling into the weld. In radiographs some detail will appear, unlike linear slag inclusions.

Nonmetallic inclusions, **Figure 25-5**, are caused under the following conditions:

- Slag and/or oxides do not have enough time to float to the surface of the molten weld pool.

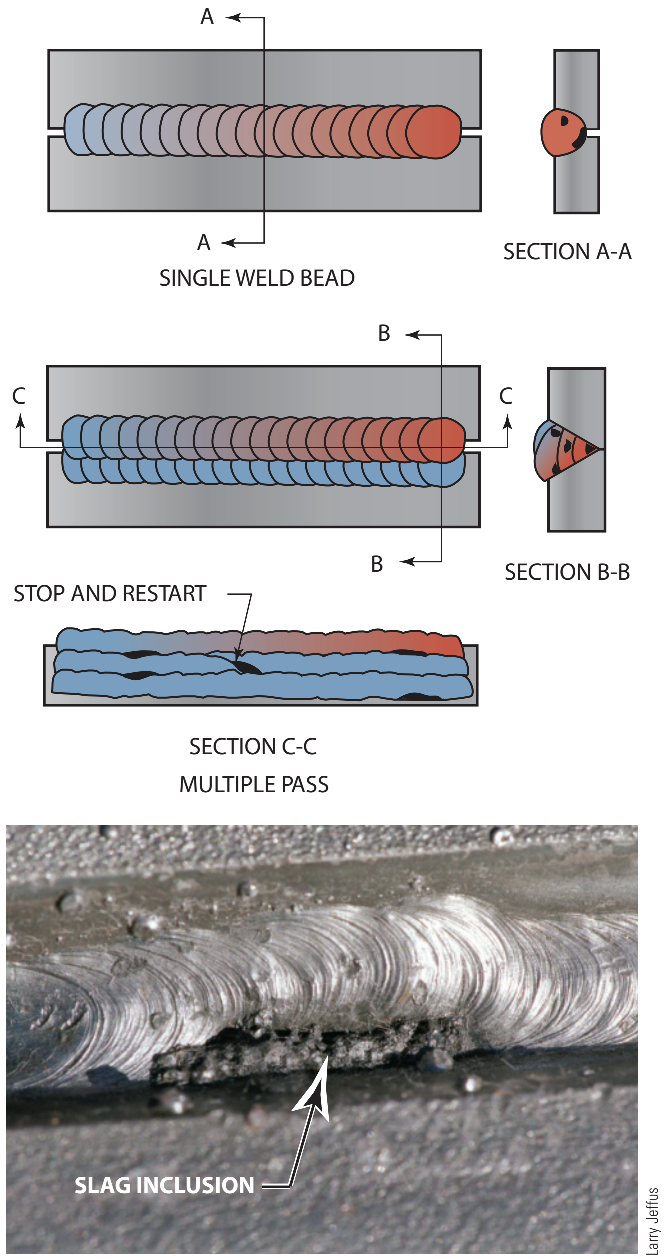


FIGURE 25-5 Nonmetallic inclusions.

- There are sharp notches between weld beads or between the weld bead and the base metal that trap the material so that it cannot float out.
- The joint was designed with insufficient room for the correct manipulation of the molten weld pool.

Refer to Table 25-2 for a listing of welds that may produce nonmetallic inclusions.

Inadequate Joint Penetration

Inadequate joint penetration occurs when the depth that the weld penetrates the joint, **Figure 25-6**, is less than that needed to fuse through the plate or into the preceding weld. A defect usually results that could reduce the required cross-sectional area of the joint or become a source of stress concentration that leads to fatigue failure. The importance of such defects depends on the notch sensitivity of the metal and the factor of safety to which the weldment has been designed. Generally, if proper welding procedures are developed and followed, then such defects do not occur.

Following are the major causes of inadequate joint penetration:

- Improper welding technique—The most common cause is a misdirected arc. Also, the welding technique may require both starting and run-out tabs to be used so that the molten weld pool is well established before it reaches the joint. Sometimes, a failure to back gouge the root sufficiently provides a deeper root face than allowed for, **Figure 25-7**.

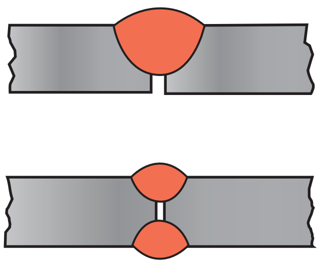


FIGURE 25-6 Inadequate joint penetration.

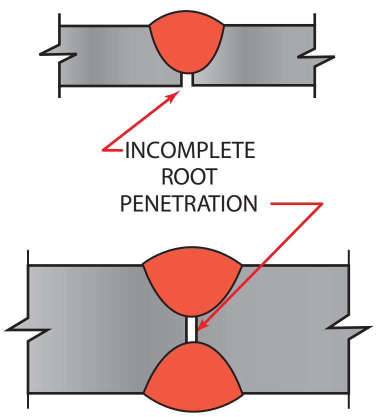


FIGURE 25-7 Incomplete root penetration.

- Not enough welding current—Metals that are thick or have a high thermal conductivity are often preheated so that the weld heat is not drawn away so quickly by the metal that it cannot penetrate the joint.
- Improper joint fit up—This problem results when the weld joints are not prepared or fitted accurately. Too small of a root gap or too large of a root face will keep the weld from penetrating adequately.
- Improper joint design—When joints are accessible from both sides, back gouging is often used to ensure 100% root fusion.

Table 25-2 lists the welding processes that might cause inadequate joint penetration.

Incomplete Fusion

Incomplete fusion is the lack of coalescence between the molten filler metal and previously deposited filler metal and/or the base metal, **Figure 25-8**. The lack of fusion between the filler metal and previously deposited weld metal is called *interpass cold lap*. The lack of fusion between the weld metal and the joint face is called *lack of sidewall fusion*. Both of these problems usually travel along all or most of the weld's length.

Following are some major causes of lack of fusion:

- Inadequate agitation—Lack of weld agitation to break up oxide layers. The base metal or weld filler metal may melt, but a thin layer of oxide may prevent coalescence from occurring.
- Improper welding techniques—Poor manipulation, such as moving too fast or using an improper electrode angle.
- Wrong welding process—For example, the use of short-circuiting transfer with GMAW to weld plate thicker than 1/4 in. (6 mm) can cause the problem because of the process's limited heat input to the weld.
- Improper edge preparation—Any notches or gouges in the edge of the weld joint must be removed. For example, if a flame-cut plate has notches along the cut, then they could result in a lack of fusion in each notch, **Figure 25-9**.
- Improper joint design—Incomplete fusion may also result from not enough heat to melt the base metal or too little space allowed by the joint designer for correct molten weld pool manipulation.
- Improper joint cleaning—Failure to clean oxides from the joint surfaces resulting from the use of an oxyfuel torch to cut the plate, or failure to remove slag from a previous weld.

Incomplete fusion can be found in welds produced by all major welding processes.

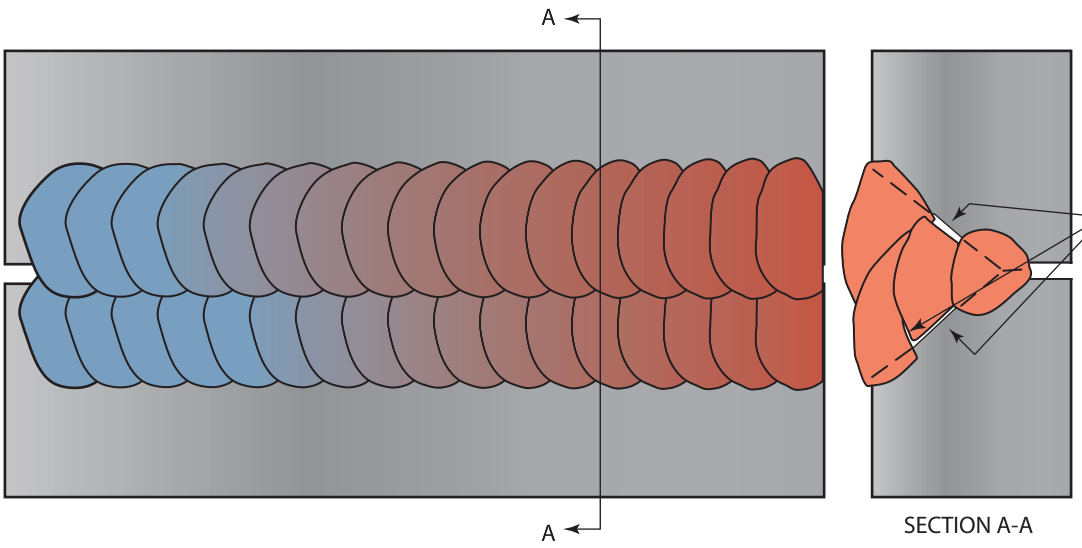


FIGURE 25-8 Incomplete fusion.

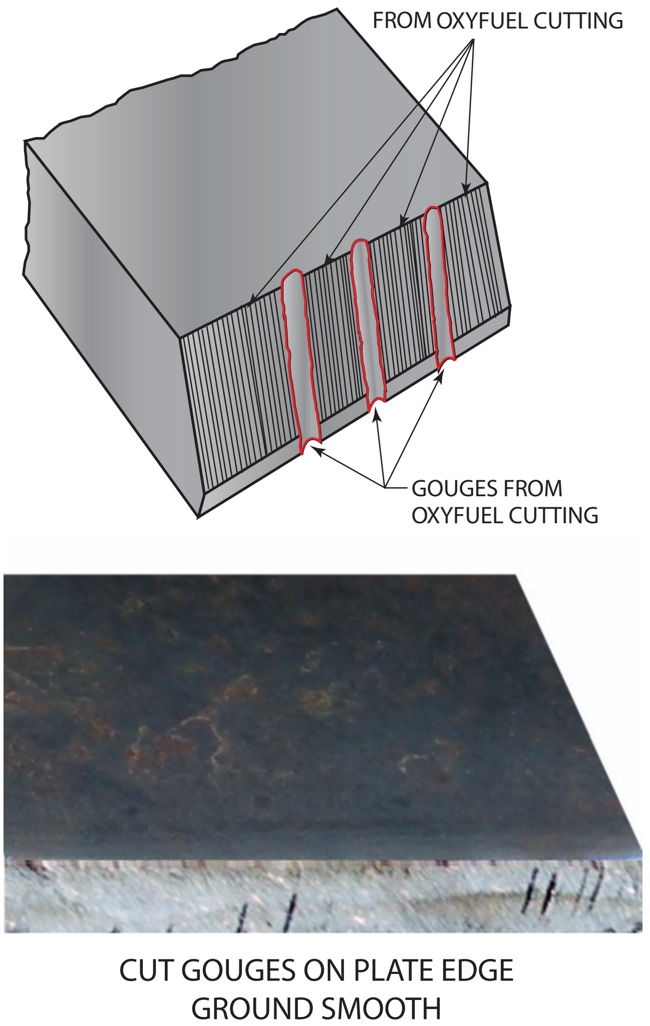


FIGURE 25-9 Remove gouges along the surface of the joint before welding.

Arc Strikes

Figure 25-10 shows arc strikes that are small, localized points where surface melting occurred away from the joint. These spots may be caused by accidentally striking the arc in the wrong place and/or by faulty ground connections. Even though arc strikes can be ground smooth, they cannot be removed. These spots will always appear if an acid etch is used. They also can be localized hardness zones or the starting point for cracking. Arc strikes, even when ground flush for a guided bend, will open to form small cracks or holes.

Overlap

Overlap, also called cold lap, occurs in fusion welds when weld deposits are larger than the joint is conditioned to accept. The weld metal then flows over the surface of the base metal without fusing to it, along the toe of the weld bead, **Figure 25-11**. It generally occurs on the horizontal leg of a

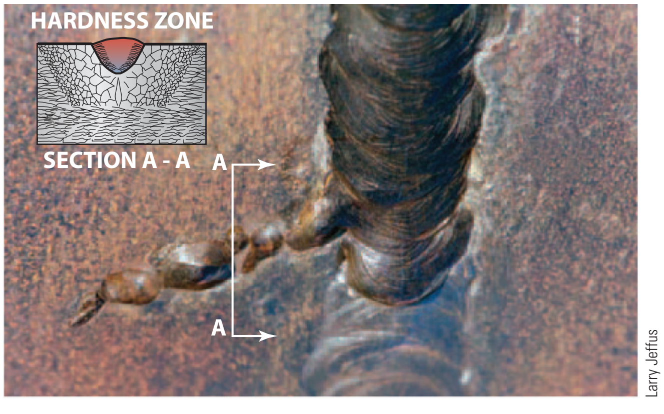


FIGURE 25-10 Arc strikes.

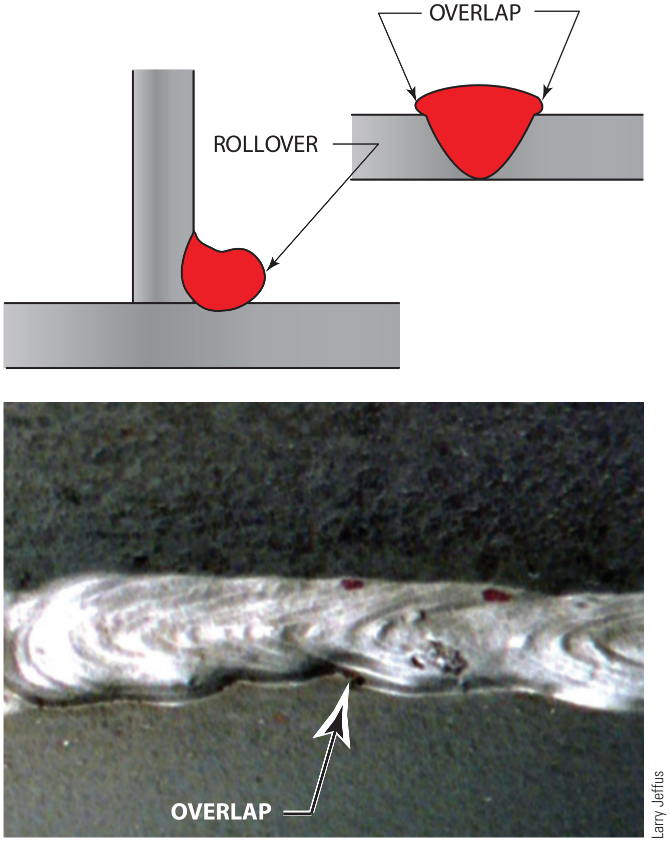


FIGURE 25-11 Rollover or overlap.

horizontal fillet weld under extreme conditions. It can also occur on both sides of flat-positioned capping passes. With GMA welding, overlap occurs when using too much electrode extension to deposit metal at low power. Misdirecting the arc into the vertical leg and keeping the electrode nearly vertical will also cause overlap. To prevent overlap, the fillet weld must be correctly sized to less than 3/8 in. (9.5 mm), and the arc must be properly manipulated.

Undercut

Undercut is a groove melted into the base metal adjacent to the weld toe or weld root and left unfilled by weld metal, **Figure 25-12**. It can result from excessive current. It is a common problem with GMA welding when insufficient oxygen is used to stabilize the arc. Incorrect welding technique, such as incorrect electrode angle or excessive weave, can also cause undercut. To prevent undercutting, the welder can weld in the flat position by using multiple instead of single passes, changing the shield gas, and improving manipulative techniques to fill the removed base metal along the toe of the weld bead.

Crater Cracks

Crater cracks are the tiny cracks that develop in the weld craters as the weld pool shrinks and solidifies, **Figure 25-13**.

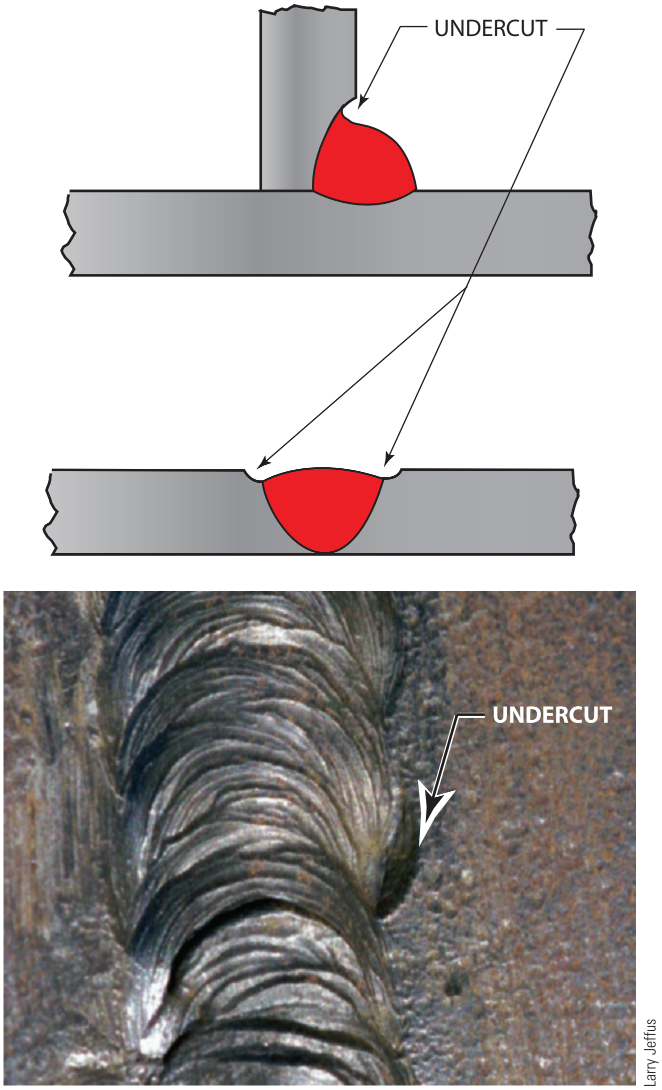


FIGURE 25-12 Undercut.

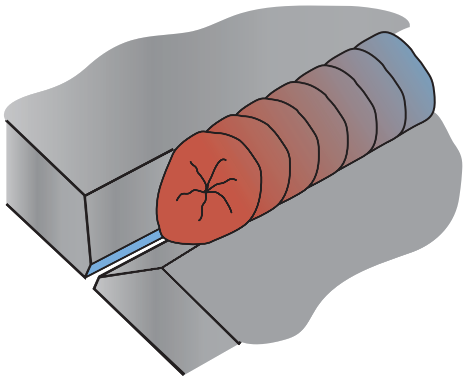


FIGURE 25-13 Crater or star cracks.

Materials with a low melting temperature are rejected toward the crater center while freezing. Because these materials are the last to freeze, they are pulled apart or separated as a result of the weld metal's shrinking as it cools. The high

shrinkage stresses aggravate crack formation. Crater cracks can be minimized, if not prevented, by not interrupting the arc quickly at the end of a weld. This allows the arc to lengthen, the current to drop gradually, and the crater to fill and cool more slowly. Some GMAW equipment has a crater filling control that automatically and gradually reduces the wire-feed speed at the end of a weld. For all other welding processes, the most effective way of preventing crater cracking is to slightly pull the weld back, allowing it to pool up on the weld bead before breaking the arc, **Figure 25-14**.

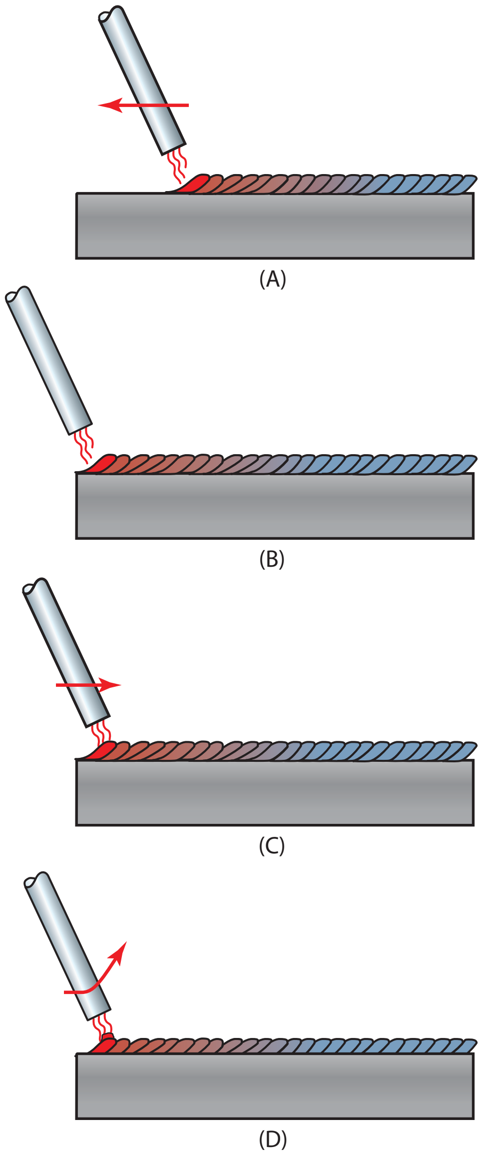


FIGURE 25-14 (A) Make a uniform weld. (B) Weld to the end of the plate. (C) Hold the arc for a second at the end of the weld. (D) Quickly (so you deposit as little weld metal as possible) move the arc back up onto the weld and break the arc.

Underfill

Underfill on a groove weld is when the weld metal deposited is inadequate to bring the weld's face or root surfaces to a level equal to that of the original plane or plate surface. For a fillet weld it is when the weld deposit has an insufficient effective throat, **Figure 25-15**. This problem can usually be corrected by slowing the travel rate or making more weld passes.

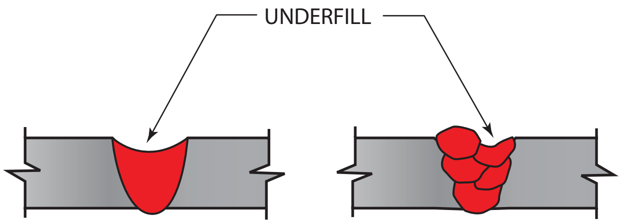


FIGURE 25-15 Underfill.

PLATE-GENERATED PROBLEMS

Not all welding problems are caused by weld metal, the process, or the welder's lack of skill in depositing that metal. The material being fabricated can be at fault, too. Some problems result from internal plate defects that the welder cannot control. Others are the result of improper welding procedures that produce undesirable hard metallurgical structures in the heat-affected zone, as discussed in other chapters. The internal defects are the result of poor steelmaking practices. Steel producers try to keep their steels as sound as possible, but the mistakes that occur in steel production are blamed, too frequently, on the welding operation.

Lamination

Laminations differ from lamellar tearing because they are more extensive and involve thicker layers of nonmetallic contaminants. Located toward the center of the plate, **Figure 25-16**, laminations are caused by insufficient cropping (removal of defects) of the pipe in ingots. The slag and oxides in the pipe are rolled out with the steel, producing the lamination. Laminations can also be caused when the ingot is rolled at too low of a temperature or pressure.

Delamination

When laminations intersect a joint being welded, the heat and stresses of the weld may cause some laminations to

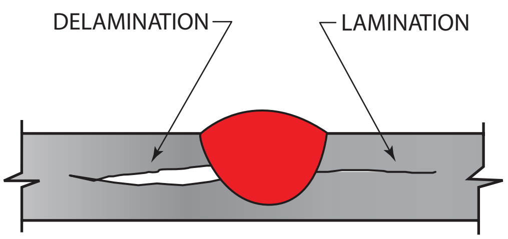


FIGURE 25-16 Lamination and delamination.

become delaminated. Contamination of the weld metal may occur if the lamination contained large amounts of slag, mill scale, dirt, or other undesirable materials. Such contamination can cause wormhole porosity or lack-of-fusion defects.

The problems associated with delaminations are not easily corrected. If a thick plate is installed in a compression load, then an effective solution can be to weld over the lamination to seal it. A better solution is to replace the steel.

Lamellar Tears

These tears appear as cracks parallel to and under the steel surface. In general, they are not in the heat-affected zone, and they have a step-like configuration. They result from the thin layers of nonmetallic inclusions that lie beneath the plate surface and have very poor ductility. Although barely noticeable, these inclusions separate when severely stressed, producing laminated cracks. These cracks are evident if the plate edges are exposed, **Figure 25-17**.

A solution to the problem is to redesign the joints to impose the lowest possible strain throughout the plate thickness. This can be accomplished by making smaller welds so that each subsequent weld pass heat-treats the previous pass to reduce the total stress in the finished weld, **Figure 25-18**. The joint design can be changed to reduce the stress on the through thickness section of the plate, **Figure 25-19**. Also refer to Chapter 22 (Welding Joint Design and Welding Symbols).

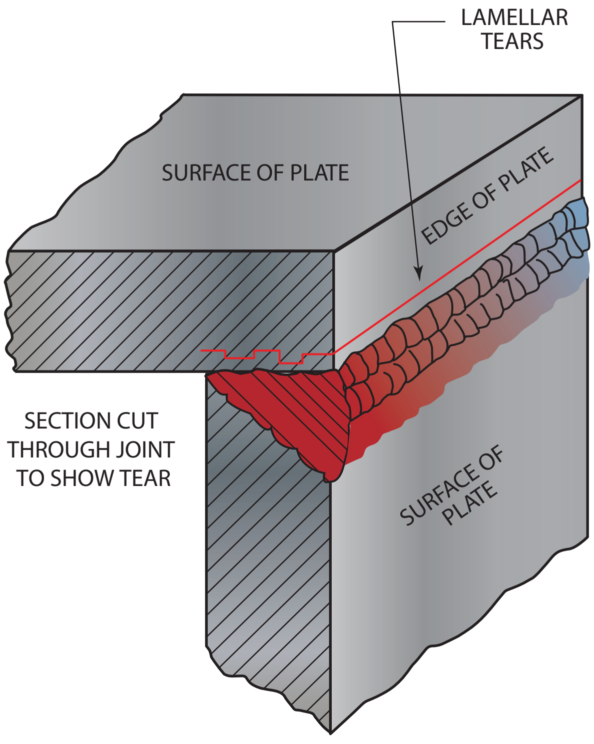


FIGURE 25-17 Example of lamellar tearing.

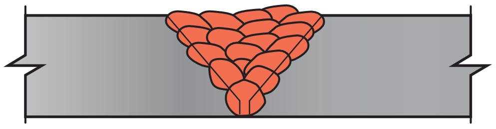


FIGURE 25-18 Using multiple welds to reduce weld stresses.

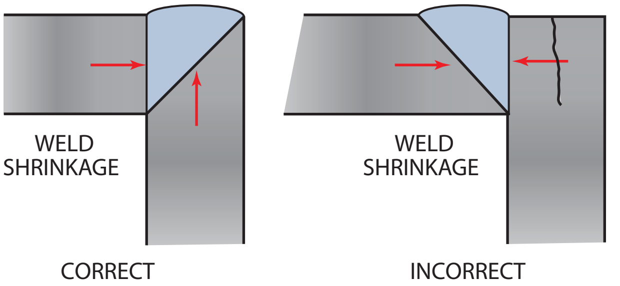


FIGURE 25-19 Correct joint design to reduce lamellar tears.

DESTRUCTIVE TESTING (DT)

Because most destructive testing results in some degree of damage or total destruction of the part being tested, only an inference can be made about whether the other weldments are fit for service because they were not actually tested. However, high reliability between the destructive test and the other weldments can be assumed provided there was strict adherence to the welding procedures.

Tensile Testing

Tensile tests are performed with specimens prepared as round bars or flat strips. The simple round bars are often used for testing only the weld metal, sometimes called "all weld metal testing." This test can be used on thick sections where base metal dilution into all of the weld metal is not possible. Round specimens are cut from the center of the weld metal. The flat bars are often used to test both the weld and the surrounding metal. Flat bars are usually cut at a 90° angle to the weld, **Figure 25-20**. **Table 25-3** shows how a number of standard smaller test bars can be used, depending on the thickness of the metal to be tested. Test bar size also depends on the size of the tensile testing equipment available for the testing.

Two flat specimens are used, commonly for testing thinner sections of metal. When testing welds, the specimen should include the heat-affected zone and the base plate. If the weld metal is stronger than the plate, then failure occurs in the plate; if the weld is weaker, then failure occurs in the weld. This test, then, is open to interpretation.

After the weld section is machined to the specified dimensions, it is placed in the tensile testing machine and pulled apart. A specimen used to determine the strength of a welded butt joint for plate is shown in **Figure 25-21**.

The tensile strength, in pounds per square inch, is obtained by dividing the maximum load required to

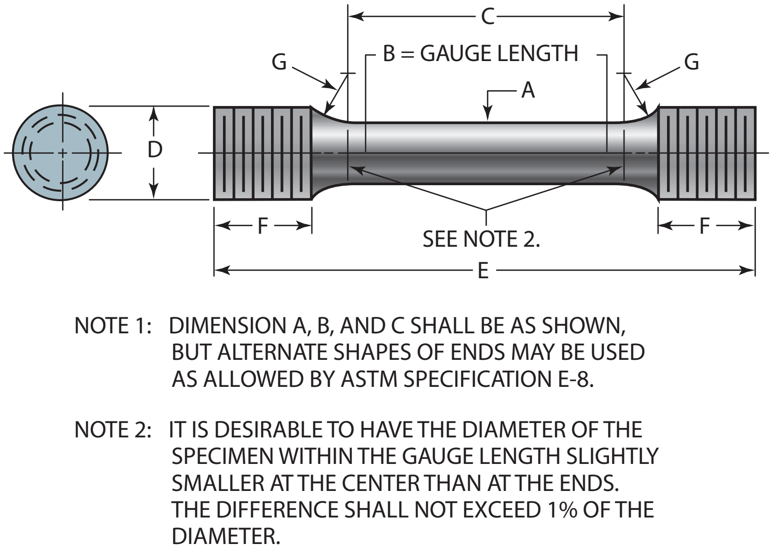


FIGURE 25-20 Tensile testing specimen.

Specimen	Dimensions of Specimen						
	in./mm A	in./mm B	in./mm C	in./mm D	in./mm E	in./mm F	in./mm G
C-1	0.500/12.7	2/50.8	2.25/57.1	0.750/19.05	4.25/107.9	0.750/19.05	0.375/9.52
C-2	0.437/11.09	1.750/44.4	2/50.8	0.625/15.8	4/101.6	0.750/19.05	0.375/9.52
C-3	0.357/9.06	1.4/35.5	1.750/44.4	0.500/12.7	3.500/88.9	0.625/15.8	0.375/9.52
C-4	0.252/6.40	1.0/25.4	1.250/31.7	0.375/9.52	2.50/63.5	0.500/12.7	0.125/3.17
C-5	0.126/3.2	0.500/12.7	0.750/19.05	0.250/6.35	1.750/44.4	0.375/9.52	0.125/3.17

TABLE 25-3 Dimensions of Tensile Testing Specimens

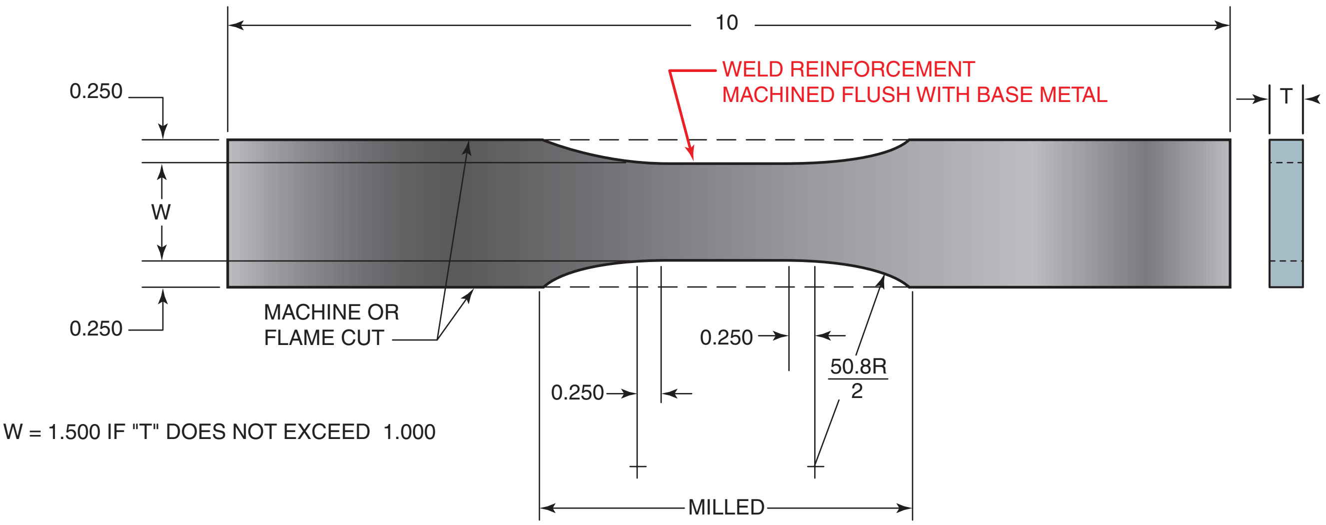


FIGURE 25-21 Tensile specimen for flat plate weld.

break the specimen by the original cross-sectional area of the specimen at the middle. The cross-sectional area is obtained by using either formula $A = \pi r^2$ or $A = D^2 \times 0.785$ (r^2 is the same as multiplying the radius times itself; D^2 is the same as multiplying the diameter times itself). Using either formula will give you the same answer.

The elongation is found by fitting the fractured ends of the specimen together, measuring the distance between gauge marks, and subtracting the gauge length. The

percent of elongation is found by dividing the elongation by the gauge length and multiplying by 100.

$$E_1 = \frac{L_f - L_o}{L_o} \times 100$$

Where:
E_1 = % of elongation
L_f = final gauge length
L_o = original gauge length

Fatigue Testing

Fatigue testing is used to determine how well a weld can resist repeated fluctuating stresses or cyclic loading. The maximum value of the stresses is less than the tensile strength of the material. Fatigue strength can be lowered by improperly made weld deposits, which may be caused by porosity, slag inclusions, lack of penetration, or cracks. Any one of these discontinuities can act as a point of stress, eventually resulting in the failure of the weld.

In the fatigue test, the part is subjected to repeated changes in applied stress. This test may be performed in one of several ways, depending on the type of service the tested part must withstand. The results obtained are usually reported as the number of stress cycles that the part will resist without failure and the total stress used.

In one type of test, the specimen is bent back and forth. This test subjects the part to alternating compression and tension. A fatigue testing machine is used for this test, **Figure 25-22**. The machine is turned on and, as it rotates, the specimen is alternately bent twice for each revolution. In this case, failure is usually rapid.

Shearing Strength Test

The two forms of **shearing strength** of welds are transverse shearing strength and longitudinal shearing strength. To test transverse shearing strength, a specimen is prepared as shown in **Figure 25-23**. The width of the specimen is measured in inches or millimeters. A tensile load is applied and the specimen is ruptured. The maximum load in pounds or kilograms is then determined.

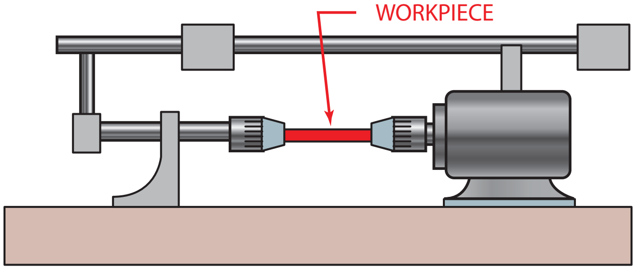


FIGURE 25-22 Fatigue testing. The specimen is placed in chucks of the machine. The machine is turned on and, as it rotates, the specimen is alternately bent twice for each revolution.

The shearing strength of the weld, in pounds per linear inch, is obtained by dividing the maximum force by twice the width of the specimen.

$$\text{Shearing strength lb/in. (kg/mm)} = \frac{\text{maximum force}}{2(\text{width of specimen})}$$

To test longitudinal shearing strength, a specimen is prepared as shown in **Figure 25-24**. The length of each weld is measured in inches or millimeters. The specimen is then ruptured under a tensile load, and the maximum force in pounds or kilograms is determined.

The shearing strength of the weld in pounds per linear inch or kilograms/millimeter is obtained by dividing the maximum force by the sum of the length of welds that ruptured.

$$\text{Shearing strength lb/in. (kg/mm)} = \frac{\text{maximum force}}{\text{length of ruptured weld}}$$

WELDED BUTT JOINTS

The three methods of testing welded butt joints are: (1) the nick-break test; (2) the guided-bend test; and (3) the free-bend test. It is possible to use variations of these tests.

Nick-Break Test

A specimen for this test is prepared as shown in **Figure 25-25A**. The specimen is supported as shown in **Figure 25-25B**. A force is then applied, and the specimen is ruptured by one or more blows of a hammer. The force may be applied slowly or suddenly. Theoretically, the rate of application could affect how the specimen breaks, especially at a critical temperature. Generally, however, there is no difference in the appearance of the fractured surface due to the method of applying the force. The surfaces of the fracture should be checked for soundness of the weld.

Guided-Bend Test

To test welded, grooved butt joints on metal that is 3/8 in. (10 mm) thick or less, two specimens are prepared and tested—one face bend and one root bend, **Figure 25-26A** and **B**. If the welds pass this test, then the welder is qualified to make groove welds on plate with a thickness range from 3/8 in. to 3/4 in. (10 mm to 19 mm). These welds need to be machined as shown in Figure 25-26A. If these specimens pass, then the welder will also be qualified to make fillet welds on materials of any (unlimited) thicknesses. For welded, grooved butt joints on metal 1/2 in. (13 mm) thick, two side-bend specimens are prepared and tested, **Figure 25-27B**. If the welds pass this test, then the welder is qualified to weld on metals of unlimited thickness.

When the specimens are prepared, caution must be taken to ensure that all grinding marks run longitudinally to the specimen so that they do not cause stress cracking. In addition, the edges must be rounded to reduce cracking

CONVERSION TABLE–MILLIMETERS TO INCHES

DIM, mm	TOL	DIM, in.
9.52		0.375
9.52	±1.58	0.375
12.70		0.500
19.05		0.750
50.60		2.000
63.50		2.500
228.60		9.000
114.30		4.500

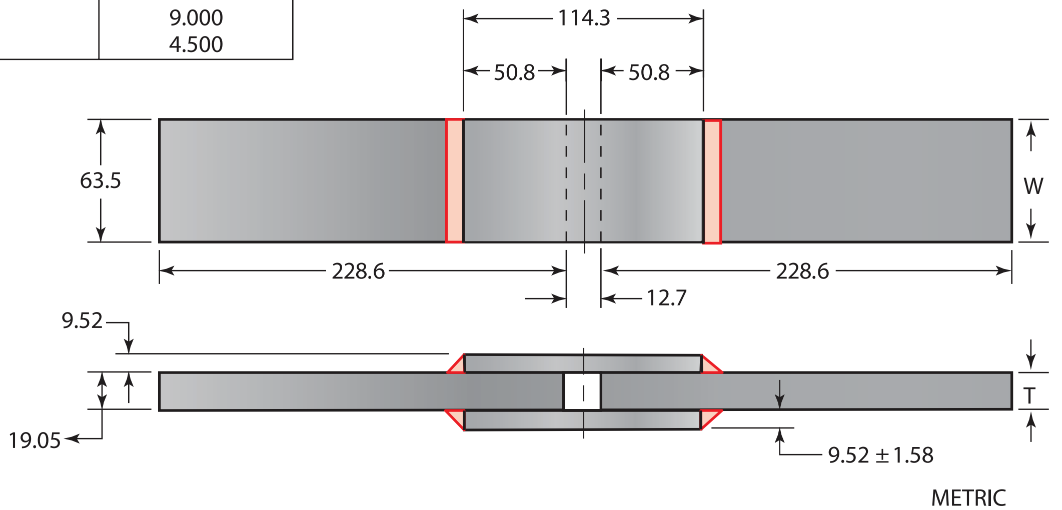
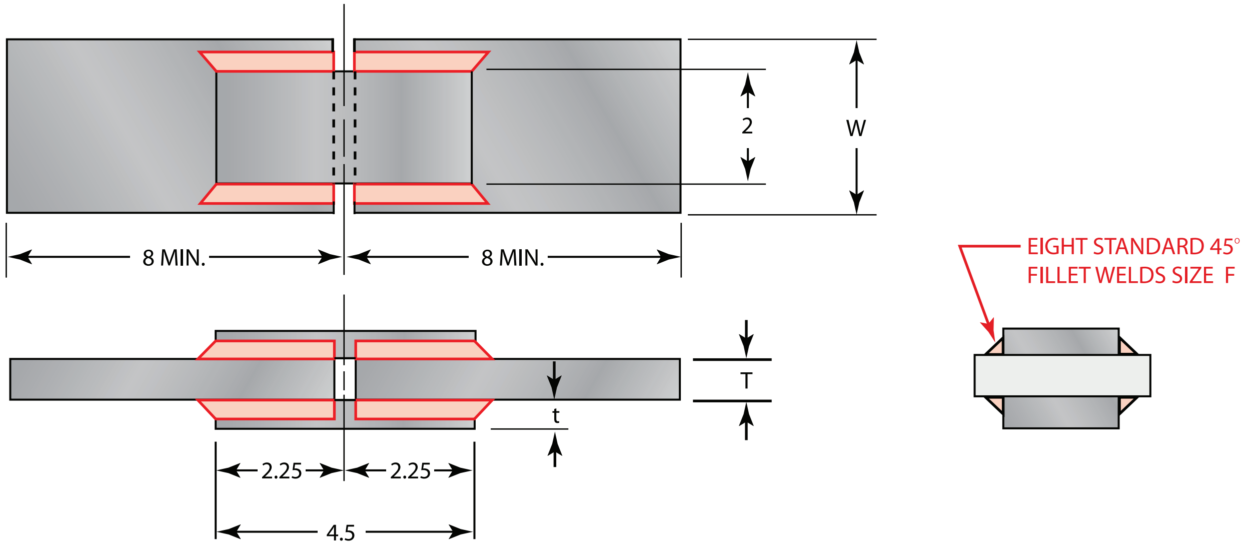


FIGURE 25-23 Transverse fillet weld shearing specimen after welding.

that tends to radiate from sharp edges. The maximum ratio of this rounded edge is 1/8 in. (3 mm).

Procedure The jig shown in **Figure 25-28** is commonly used to bend most specimens. Not all guided-bend testers have the same bending radius. Codes specify different bending radii depending on material type and thickness. Place the specimens in the jig with the weld in the middle. Face-bend specimens should be placed with the face of the weld toward the gap. Root-bend specimens should be positioned so that the root of the weld is directed toward the



DIMENSIONS			
	in. mm.	in. mm.	in. mm.
THICKNESS (F)	1/8 - 3.17	1/4 - 6.35	3/8 - 9.52
THICKNESS (t)	3/8 - 9.52	1/2 - 12.7	3/4 - 19.02
THICKNESS (T)	3/8 - 9.52	3/4 -19.05	1 - 25.4
WIDTH (W)	3 - 76.2	3 - 76.2	3 - 76.2

FIGURE 25-24 Longitudinal fillet weld shear specimen.

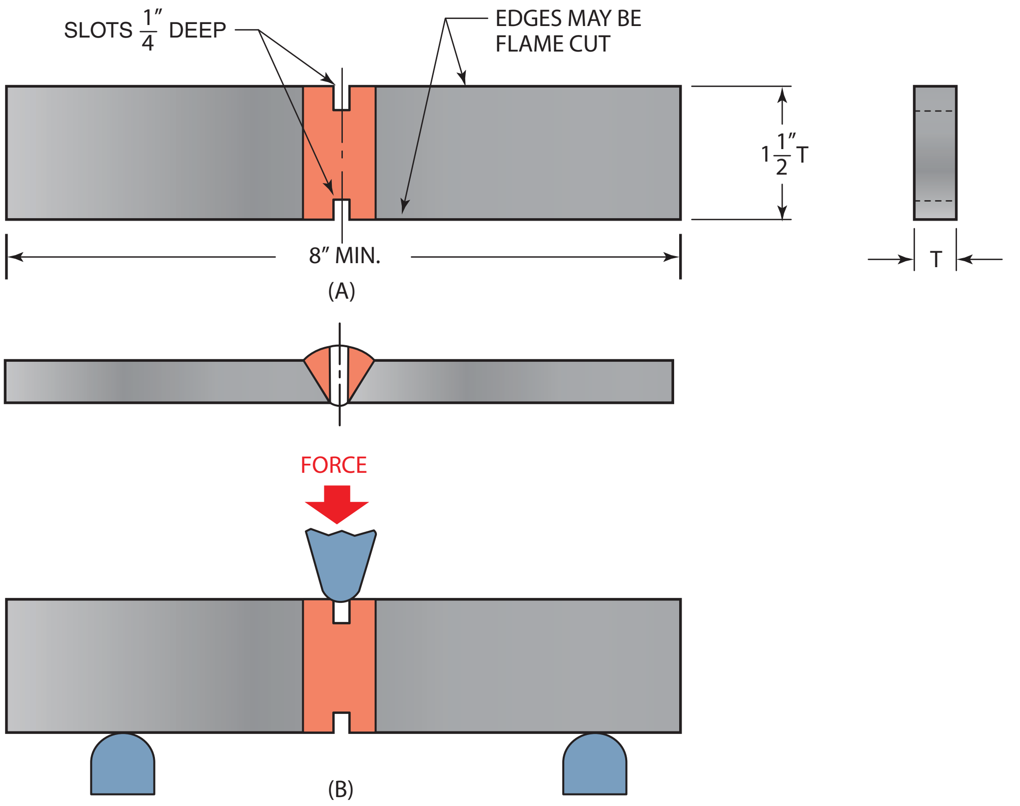


FIGURE 25-25 (A) Nick-break specimen for butt joints in plate. (B) Method of rupturing nick-break specimen.

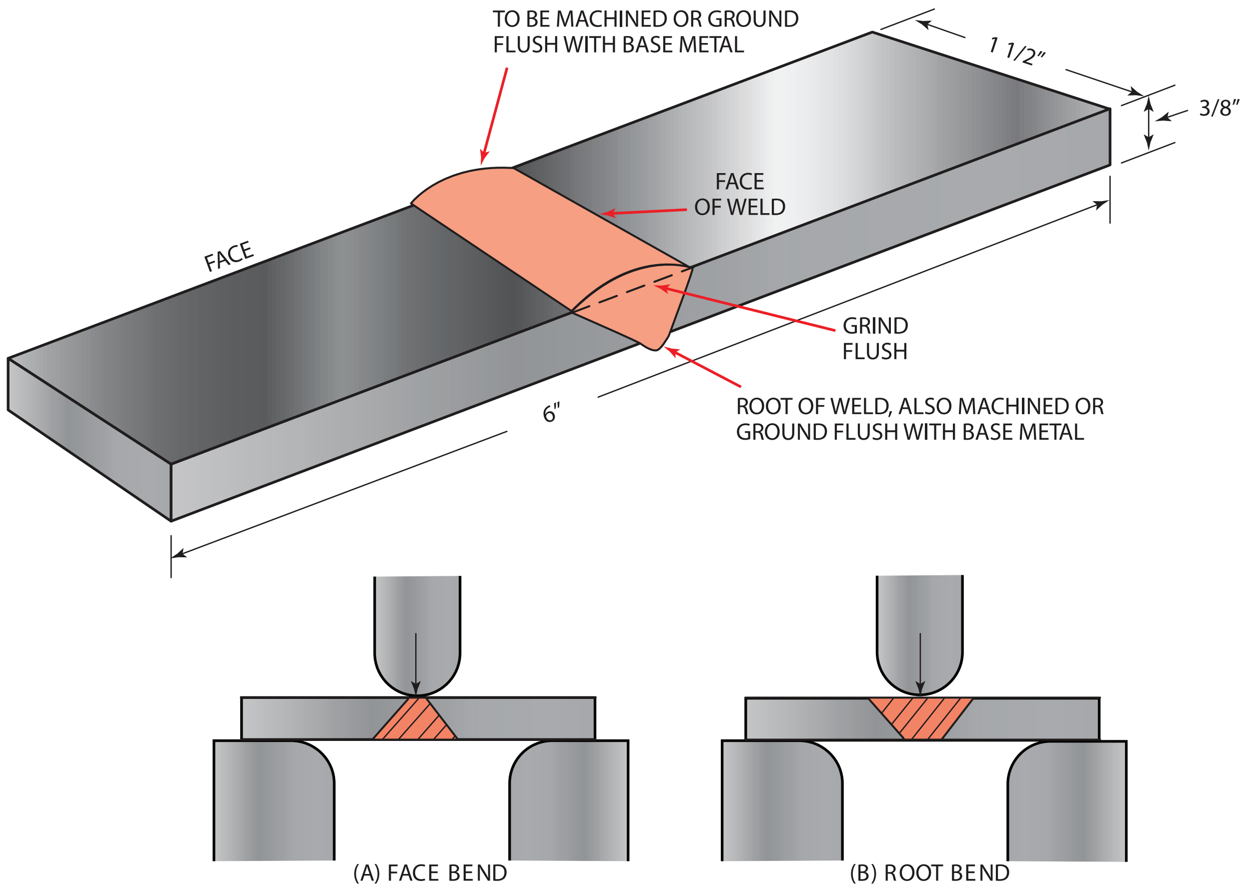
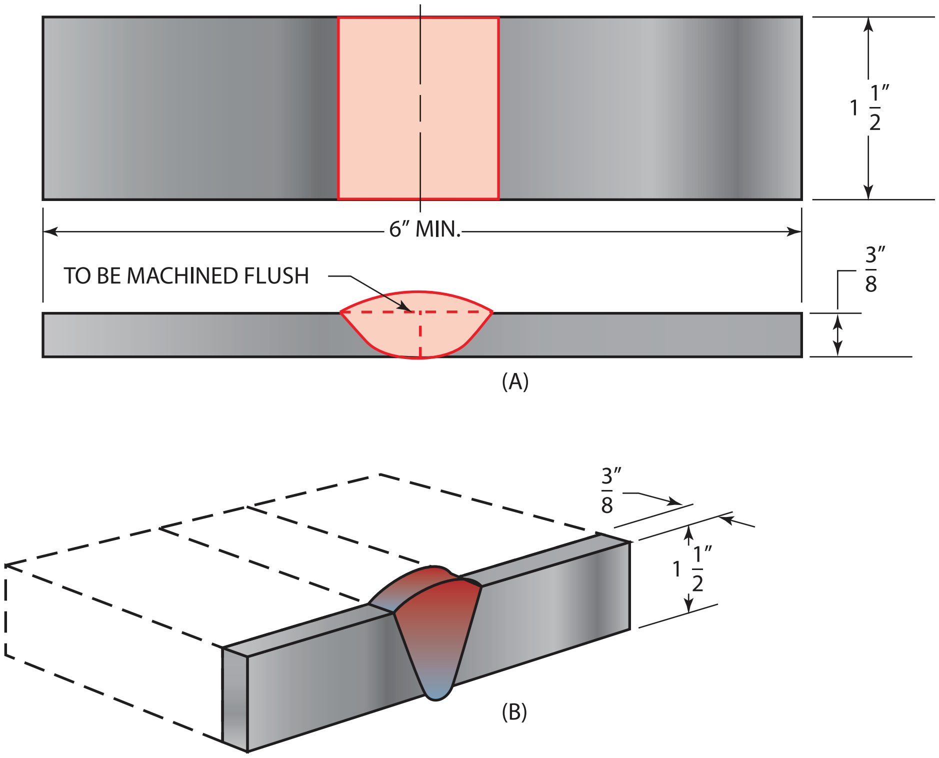


FIGURE 25-26 Root and face bend specimens for 3/8-in. (10-mm) plate.



mm	CONVERSION, in.
1.5	1/16
3.1	1/8
9.5	3/8
12.7	1/2
38.0	1 1/2
152.0	6

FIGURE 25-27 (A) Root and face bend specimens. (B) Side bend specimen.

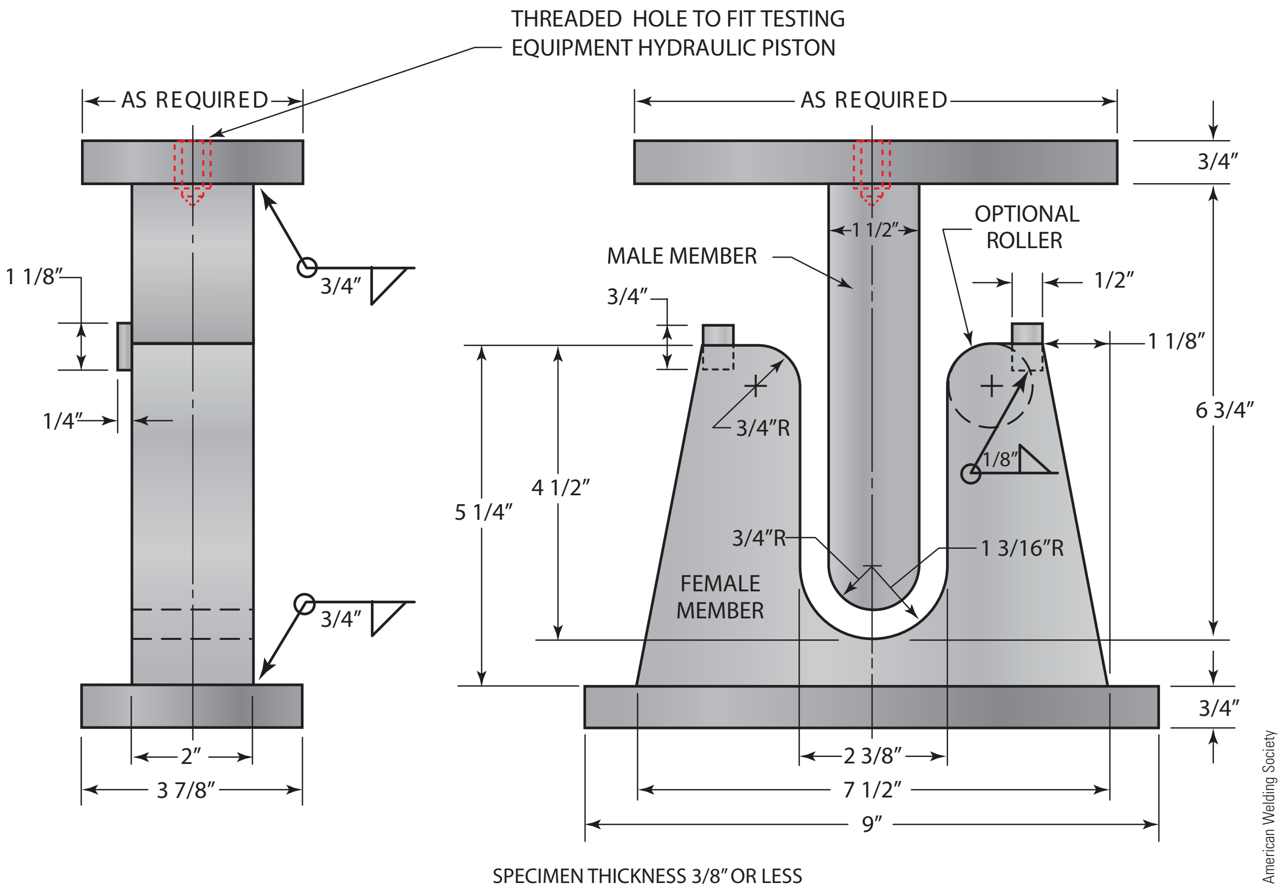
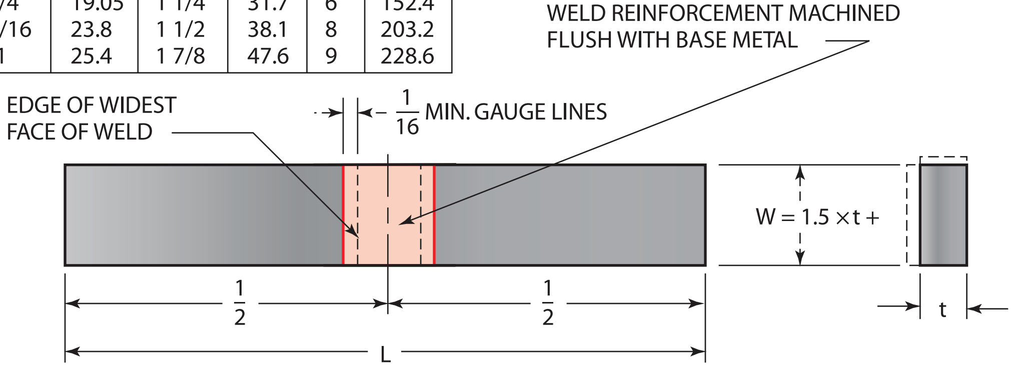


FIGURE 25-28 Fixture for guided-bend test.

CONVERSION TABLE							
in.	mm	in.	mm	in.	mm	in.	mm
1/4	6.35	9/16	14.2	1 1/8	28.5	2	50.8
3/8	9.52	3/4	19.05	1 1/4	31.7	6	152.4
1/2	12.7	15/16	23.8	1 1/2	38.1	8	203.2
5/8	15.8	1	25.4	1 7/8	47.6	9	228.6



DIMENSIONS							
T, in.	1/4	3/8	1/2	5/8	3/4	1	1 1/4
W, in.	3/8	9/16	3/4	15/16	1 1/8	1 1/2	1 7/8
L, min, in.	6	8	9	10	12	13 1/2	15
B, min, in.	1 1/4	1 1/4	1 1/4	2	2	2	2

FIGURE 25-29 Free-bend test specimen.

gap. Side-bend specimens are placed with either side facing up. The guided-bend specimen must be pushed all the way through open (roller-type) bend testers and within 1/8 in. (3 mm) of the bottom on fixture-type bend testers.

Once the test is completed, the specimen is removed. The convex surface is then examined for cracks or other discontinuities and judged acceptable or unacceptable according to specified criteria. Some surface cracks and openings are allowable under codes.

Free-Bend Test

The free-bend test is used to test welded joints in plate. A specimen is prepared as shown in **Figure 25-29**. Note that the width of the specimen is 1.5 multiplied by the thickness of the specimen. Each corner lengthwise should be rounded in a radius not exceeding one-tenth the thickness of the specimen. Tool marks should run the length of the specimen.

Gauge lines are drawn on the face of the weld, **Figure 25-30**. The distance between the gauge lines is 1/8 in. (3.17 mm) less than the face of the weld. The initial bend of the specimen is completed in the device illustrated in **Figure 25-31**. The gauge line surface should be directed toward the supports. The weld is located in the center of the supports and loading block.

Alternate Bend

The initial bend may be made by placing the specimen in the jaws of a vise with one-third the length projecting from the jaws. The specimen is then bent away from the gauge lines through an angle of 30° to 45° by blows of a hammer. The specimen is then inserted into the jaws of a vise and pressure is applied by tightening the vise. The pressure is continued until a crack or depression appears on the convex face of the specimen. The load is then removed.

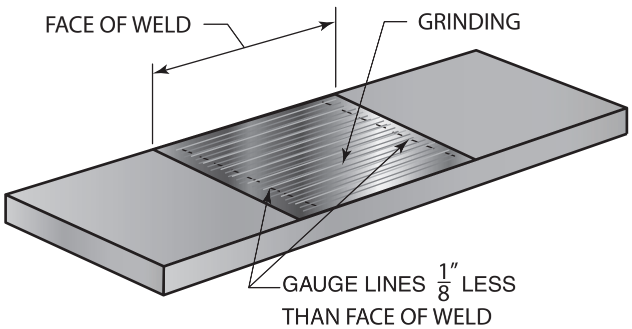
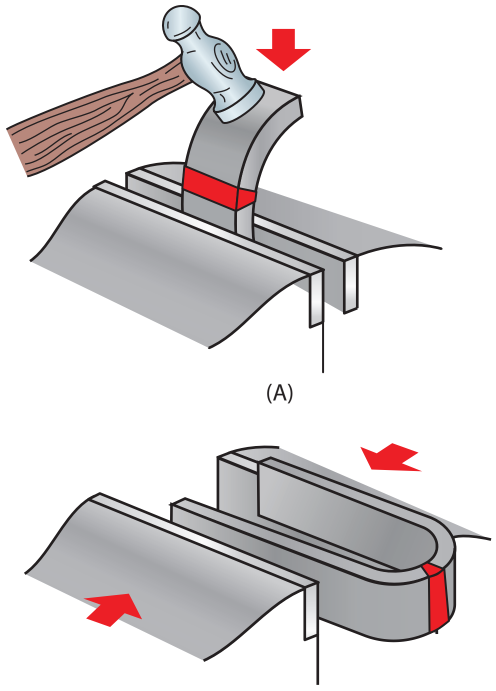


FIGURE 25-30 Gauge lines are drawn on the weld face of a free-bend specimen.

The elongation is determined by measuring the minimum distance between the gauge lines along the convex surface of the weld to the nearest 0.01 in. (0.254 mm) and subtracting the initial gauge length. The percent of elongation is obtained by dividing the elongation by the initial gauge length and multiplying by 100.

Fillet Weld Break Test

The specimen for this test is made as shown in **Figure 25-32A**. In **Figure 25-32B**, a force is applied to the specimen



CONVERSION TABLE	
mm	in.
12.7	0.500
20.0	0.787
32.0	1.25
76.0	3.000

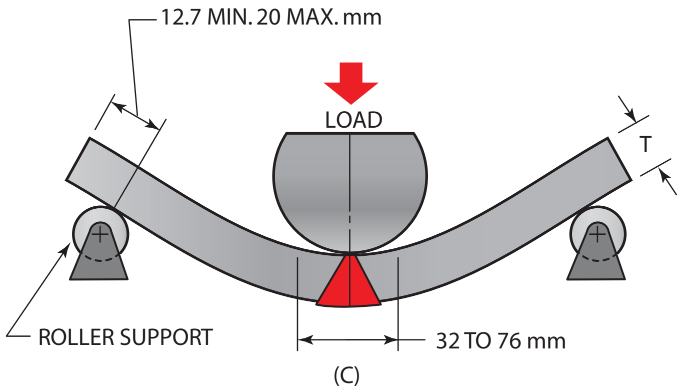


FIGURE 25-31 Free-bend test: (A) initial bend can be made in this manner; (B) a vise can be used to make the final bend; and (C) another method used to make the bend.

until the specimen ruptures. Any convenient means of applying the force may be used, such as an arbor press, a testing machine, or hammer blows. The break surface should then be examined for soundness—that is, slag inclusions, overlap, porosity, lack of fusion, or other discontinuities.

Testing by Etching

Specimens to be tested by **etching** are etched for two purposes: (1) to determine the soundness of a weld or (2) to determine the location of a weld.

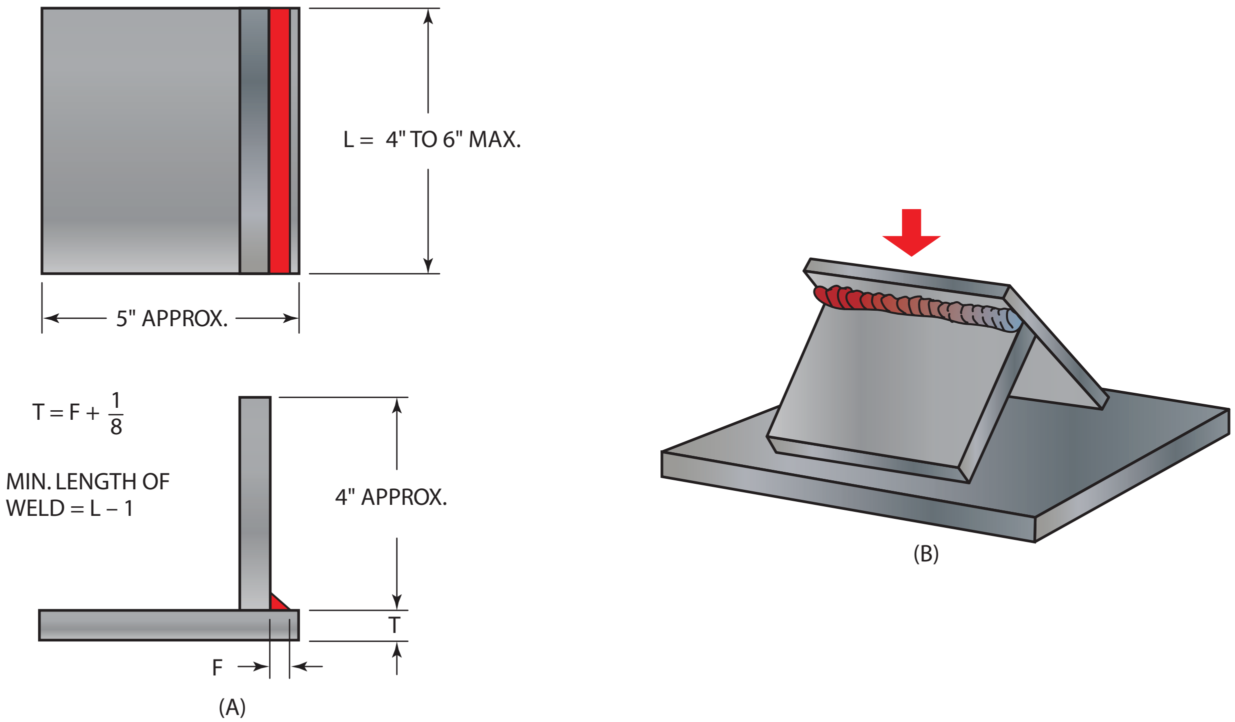


FIGURE 25-32 (A) Fillet weld break test and (B) method of rupturing fillet weld break specimen.

A test specimen is produced by cutting a portion from the welded joint so that a complete cross-section is obtained. The face of the cut is then filed and polished with fine abrasive cloth. The specimen can then be placed in the etching solution. The etching solution or reagent makes the boundary between the weld metal and base metal visible, if the boundary is not already distinctly visible.

The most commonly used etching solutions are hydrochloric acid, ammonium persulfate, and nitric acid.

Hydrochloric Acid Equal parts by volume of concentrated hydrochloric (muriatic) acid and water are mixed. The welds are immersed in the reagent at or near the boiling temperature. The acid usually enlarges gas pockets and dissolves slag inclusions, enlarging the resulting cavities.

CAUTION

When mixing the muriatic acid into the water, be sure safety glasses and gloves are worn to prevent any injuries from occurring.

Ammonium Persulfate A solution is prepared consisting of one part of ammonium persulfate (solid) to nine parts of water by weight. The surface of the weld is rubbed with cotton saturated with this reagent at room temperature.

Nitric Acid A great deal of care should be exercised when using nitric acid because severe burns can result if it is used carelessly. One part of concentrated nitric acid is mixed with nine parts of water by volume.

CAUTION

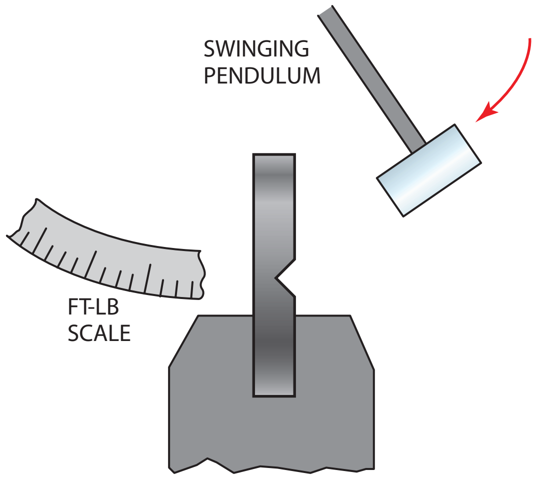
When diluting an acid, always pour the acid slowly into the water while continuously stirring the water. Carelessly handling this material or pouring water into the acid can result in burns, excessive fuming, or explosion.

The reagent is applied to the surface of the weld with a glass-stirring rod at room temperature. Nitric acid has the capacity to etch rapidly and should be used on polished surfaces only.

After etching, the weld is rinsed in clear, hot water. Excess water is removed, and the etched surface is then immersed in ethyl alcohol and dried.

Impact Testing

A number of tests can be used to determine the impact capability of a weld. One common test is the Izod test, **Figure 25-33A**, in which a notched specimen is struck by an anvil mounted on a pendulum. The energy in foot-pounds read on the scale mounted on the machine required to break the specimen is an indication of the impact resistance of the metal. This test compares the toughness of the weld metal with the base metal.



(A)

(B)

FIGURE 25-33 Impact testing: (A) specimen mounted for Izod impact toughness and (B) a typical impact tester used for measuring the toughness of metals.

Another type of impact test is the Charpy test. This test is similar to the Izod test. The major differences between the tests are that the Izod test specimen is gripped on one end and is held vertically and usually tested at room temperature, and the Charpy test specimen is held horizontally, supported on both ends, and is usually tested at a specific temperature. All impact test specimens must be produced according to ASTM specifications. A typical impact tester is shown in **Figure 25-33B**.

NONDESTRUCTIVE TESTING (NDT)

Nondestructive testing of welds is a method used to test materials for surface defects such as cracks, arc strikes, undercuts, and lack of penetration. Internal or subsurface defects can include slag inclusions, porosity, and unfused metal in the interior of the weld.

Visual Inspection (VT)

Visual inspection is the most frequently used nondestructive testing method and is the first step in almost every other inspection process. The majority of welds receive only visual inspection. In this method, if the weld looks good it passes; if it looks bad it is rejected. This procedure is often overlooked when more sophisticated nondestructive testing methods are used. However, it should not be overlooked.

An active visual inspection schedule can reduce the finished weld rejection rate by more than 75%. Visual inspection can easily be used to check for fit up, interpass acceptance, welder technique, and other variables that will affect the weld quality. Minor problems can be identified and corrected before a weld is completed. This eliminates costly repairs or rejection.

Visual inspection should be used before any other nondestructive or mechanical tests are used to eliminate (reject) the obvious problem welds. Eliminating welds that have excessive surface discontinuities that will not pass the code or standards being used saves preparation time.

The AWS has set a number of visual inspection standards for entry-level welders to meet or exceed. To pass Level I certification standards, each weld and/or weld pass is to be inspected visually using the following criteria:

- There shall be no cracks or incomplete fusion.
- There shall be no incomplete joint penetration in groove welds except as permitted for partial joint penetration groove welds.
- The Test Supervisor shall examine the weld for acceptable appearance and shall be satisfied that the welder is skilled in the process and procedure specified for the test.
- Undercut shall not exceed the lesser of 10% of the base metal thickness or 1/32 in. (0.8 mm).
- When visual examination is the only criterion for acceptance, all weld passes are subject to visual examination at the direction of the Test Supervisor.
- The frequency of porosity shall not exceed one in each 4 in. (100 mm) of weld length, and the maximum diameter shall not exceed 3/32 in. (2.4 mm).
- Welds shall be free from overlap.

Penetrant Inspection (PT)

Penetrant inspection is used to locate minute surface cracks and porosity. Two types of penetrants are now in use, the color-contrast version and the fluorescent version. Color-contrast, often red, penetrants contain a colored dye that shows under ordinary white light. Fluorescent penetrants contain a more effective fluorescent dye that shows under black light.

The following steps outline the procedure to be followed when using a penetrant.

1. Precleaning—The test surface must be clean and dry. Suspected flaws must be cleaned and dried so that they are free of oil, water, or other contaminants.
2. The test surface must be covered with a film of penetrant by dipping, immersing, spraying, or brushing.
3. The test surface is then gently wiped, washed, or rinsed free of excess penetrant. It is dried with cloths or hot air.
4. A developing powder applied to the test surface acts as a blotter to speed the tendency of the penetrant to seep out of any flaws open to the test surface.
5. Depending on the type of penetrant applied, visual inspection is made under ordinary white light or near-ultraviolet black light when viewed under this light, **Figure 25-34**. The penetrant fluoresces to a yellow-green color, which clearly defines the defect.

Magnetic Particle Inspection (MT)

Magnetic particle inspection uses finely divided ferromagnetic particles (powder) to indicate defects open to the surface or just below the surface on magnetic materials.

A magnetic field is induced in a part by passing an electric current through or around it. The magnetic field is always at right angles to the direction of current flow. Ferromagnetic powder registers an abrupt change in the resistance in the path of the magnetic field, such as would be caused by a crack lying at an angle to the direction of the magnetic poles at the crack. Finely divided ferromagnetic particles applied to the area will be attracted and outline the crack.

In **Figure 25-35**, the flow or discontinuity interrupting the magnetic field in a test part can be either longitudinal or circumferential. A different type of magnetization is used to detect defects that run down the axis, as opposed to those occurring around the girth of a part. For some applications you may need to test in both directions.

In **Figure 25-36A**, longitudinal magnetization allows detection of flaws running around the circumference of a part. The user places the test part inside an electrified coil. This induces a magnetic field down the length of the test part. In **Figure 25-36B**, circumferential magnetization allows detection of flaws occurring down the length of a test part. An electric current is sent down the length of the part to be inspected. The magnetic field thus induced allows defects along the length of the part to be detected.

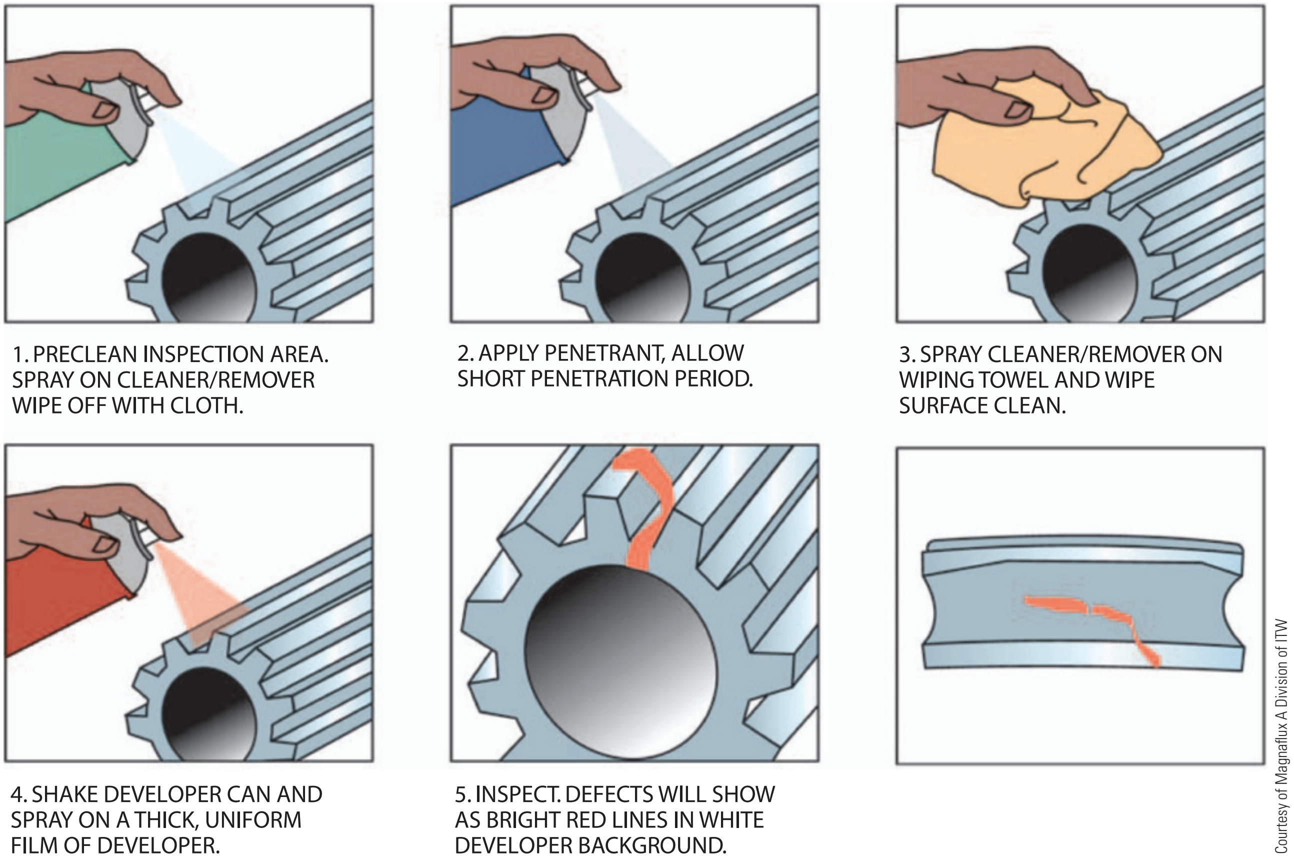


FIGURE 25-34 Penetrant testing.

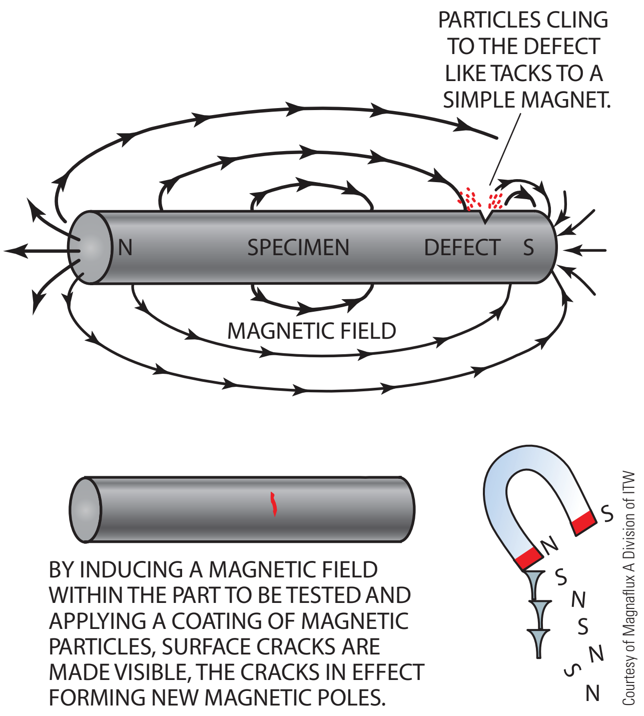


FIGURE 25-35 Flaws and discontinuities interrupt magnetic fields.

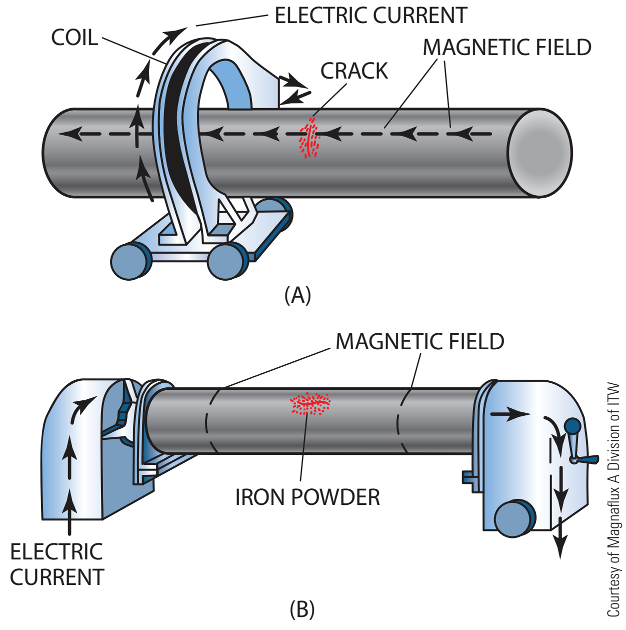


FIGURE 25-36 (A) Longitudinal magnetic field. (B) Circumferential magnetic field.

Radiographic Inspection

Radiographic inspection (RT) is a method for detecting flaws inside weldments. Radiography gives a picture of all discontinuities that are parallel (vertical) or nearly parallel to the source. Discontinuities that are perpendicular (flat) or nearly perpendicular to the source may not be seen on the X-ray film. Instead of using visible light rays, the operator uses invisible, short-wavelength rays developed by X-ray machines, radioactive isotopes (gamma rays), and variations of these methods. These rays are capable of penetrating solid materials and reveal most flaws in a weldment on an X-ray film or a fluorescent screen. Flaws are revealed on films as dark or light areas against a contrasting background after exposure and processing, **Figure 25-37**.

The defect images in radiographs measure differences in how the X-rays are absorbed as they penetrate the weld. The weld itself absorbs most X-rays. If something less dense than the weld is present, such as a pore or lack of fusion defect, fewer X-rays are absorbed, darkening the film. If something more dense is present, such as heavy ripples on the weld surface, more X-rays will be absorbed, lightening the film.

Therefore, the foreign material's relative thickness (or lack of it) and differences in X-ray absorption determine the radiograph image's final shape and shading. Skilled readers of radiographs can interpret the significance of the light and dark regions by their shape and shading. The X-ray image is a shadow of the flaw. The farther the flaw is from the X-ray film, the fuzzier the image appears. Those skilled at interpreting weld defects in radiographs must also be very knowledgeable about welding.

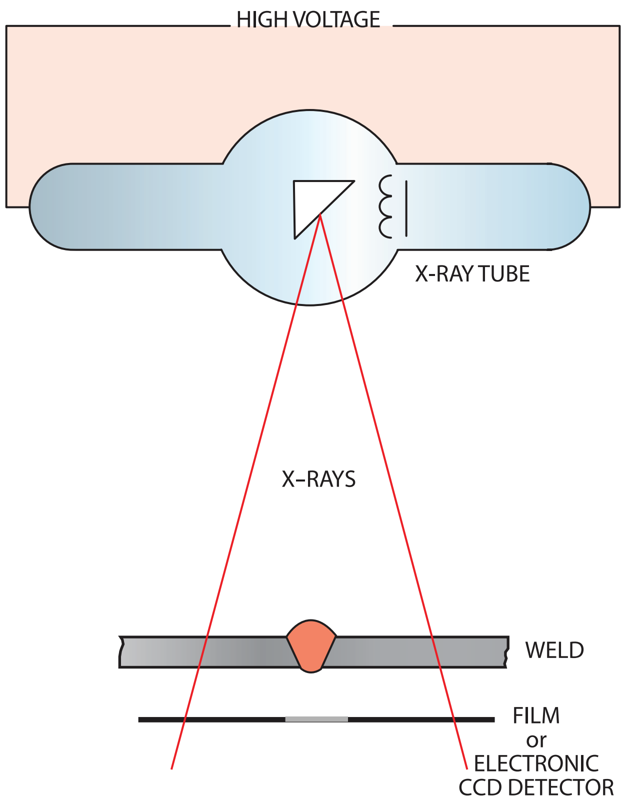


FIGURE 25-37 Schematic of an X-ray system.

Figure 25-38 shows samples of common weld defects and a representative radiograph for each.

Four factors affect the selection of the radiation source:

- Thickness and density of the material
- Absorption characteristics
- Time available for inspection
- Location of the weld

Portable equipment is available for examining fixed or hard-to-move objects. The selection of the correct equipment for a particular application is determined by specific voltage required, degree of utility, economics of inspection, and production rates expected, **Figure 25-39** and **Figure 25-40**.

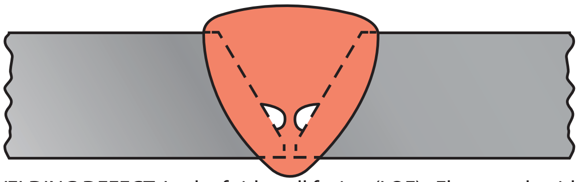
Ultrasonic Inspection

Ultrasonic inspection (UT) is fast and uses few consumable supplies, which makes it inexpensive for schools to use. However, because of the time required for most UT testing, it is not as economical in the field as the nondestructive testing method. This inspection method uses electronically produced high-frequency sound waves, which penetrate metals and many other materials at speeds of several thousand feet (meters) per second.

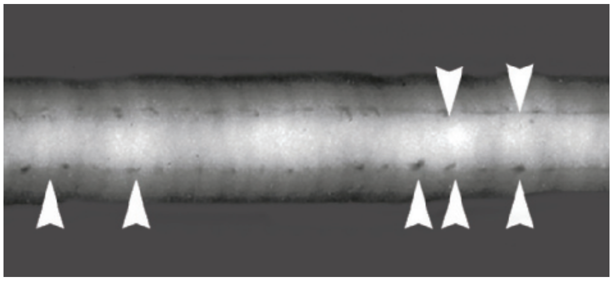
The two types of ultrasonic equipment are pulse and resonance. The pulse-echo system, most often used in the welding field, uses sound generated in short bursts or pulses. Because the high-frequency sound used is at a relatively low power, it has little ability to travel through air, so it must be conducted from the probe into the part through a medium such as oil or water. A portable ultrasonic inspection unit is shown in **Figure 25-41**.

Sound is directed into the part with a probe held in a preselected angle or direction so that flaws will reflect some energy back to the probe. These ultrasonic devices operate very much like depth sounders, or "fish finders." The speed of sound through a material is a known quantity. These devices measure the time required for a pulse to return from a reflective surface. Internal computers calculate the distance and present the information on a display screen where an operator can interpret the results. The signals can be "monitored" electronically to operate alarms, print systems, or recording equipment. Sound not reflected by flaws continues into the part. If the angle is correct, then the sound energy will be reflected back to the probe from the opposite side. Flaw size is determined by plotting the length, height, width, and shape using trigonometric rules.

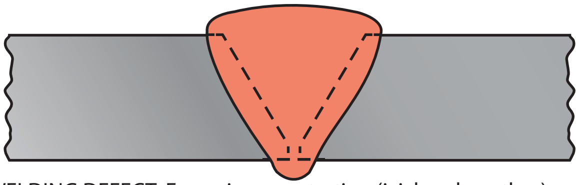
Figure 25-42 shows the path of the sound beam in butt welding testing. The operator must know the exit point of the sound beam, the exact angle of the refracted beam, and the thickness of the plate when using shear waveforms and compression waveforms.



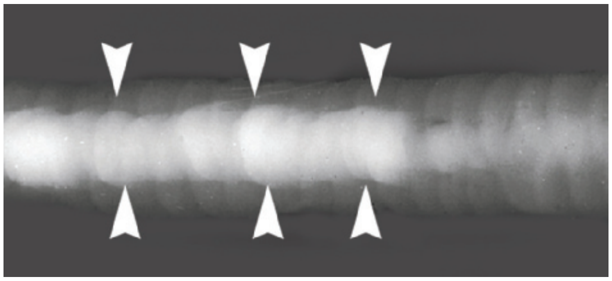
WELDING DEFECT: Lack of sidewall fusion (LOF). Elongated voids between the weld beads and the joint surfaces to be welded.



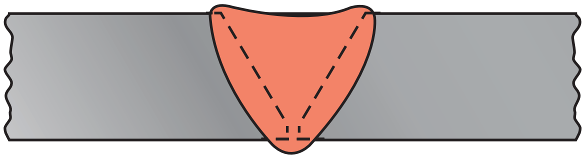
RADIOGRAPHIC IMAGE: Elongated parallel, or single, darker density lines sometimes with darker density spots dispersed along the LOF lines which are very straight in the lengthwise direction and not winding like elongated slag lines. Although one edge of the LOF lines may be very straight like LOP, lack of sidewall fusion images will not be in the center of the width of the weld image.



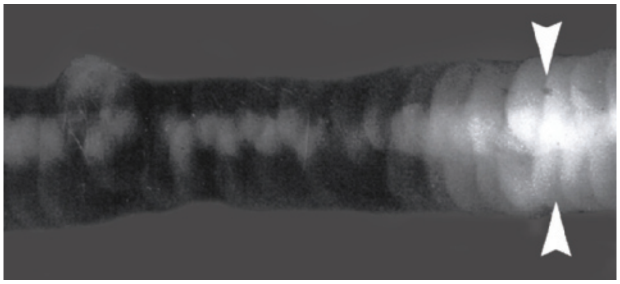
WELDING DEFECT: Excessive penetration (icicles, drop-thru). Extra metal at the bottom (root) of the weld.



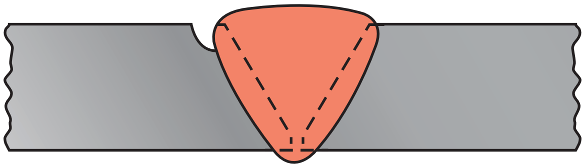
RADIOGRAPHIC IMAGE: A lighter density in the center of the width of the weld image either extended along the weld or in isolated circular "drops".



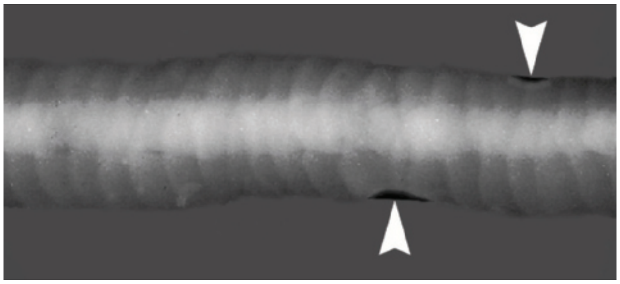
WELDING DEFECT: External concavity or insufficient fill. A depression in the top of the weld, or cover pass, indicating a thinner more normal section thickness.



RADIOGRAPHIC IMAGE: A weld density darker than the density of the pieces being welded and extending across the full width of the weld image.

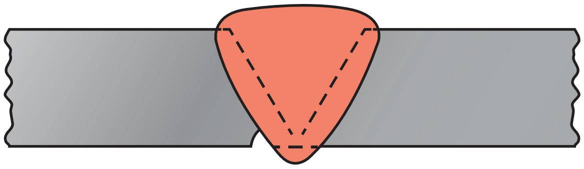


WELDING DEFECT: External undercut. A gouging out of the piece to be welded, alongside the edge of the top or "external" surface of the weld.

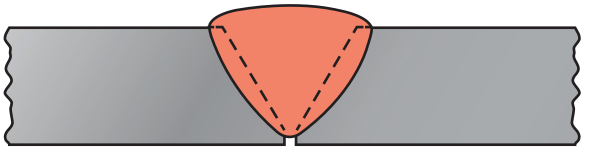


RADIOGRAPHIC IMAGE: An irregular darker density along the edge of the weld image. The density will always be darker than the density of the pieces being welded.

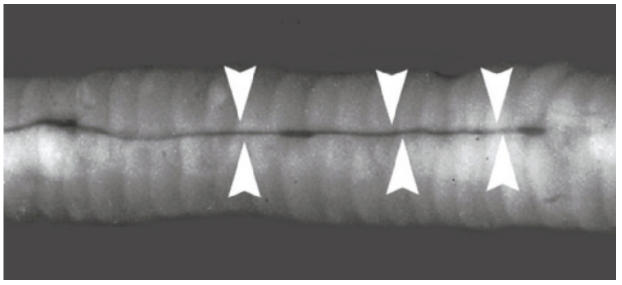
FIGURE 25-38 Welding defects with radiographic images. (*Continued*)



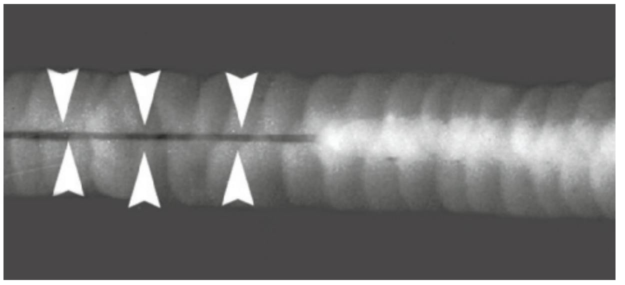
WELDING DEFECT: Internal (root) undercut. A gouging out of the parent metal, alongside the edge of the bottom or "internal" surface of the weld.



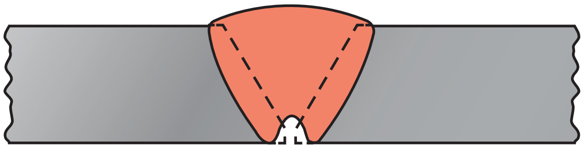
WELDING DEFECT: Incomplete or lack of penetration (LOP). The edges of the pieces have not been welded together, usually at the bottom of single V-groove welds.



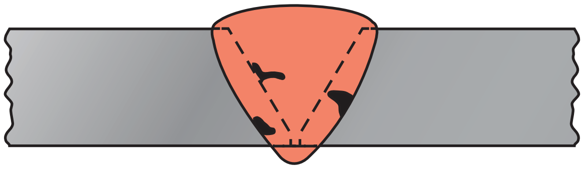
RADIOGRAPHIC IMAGE: An irregular darker density near the center of the width of the weld image and along the edge of the root pass image.



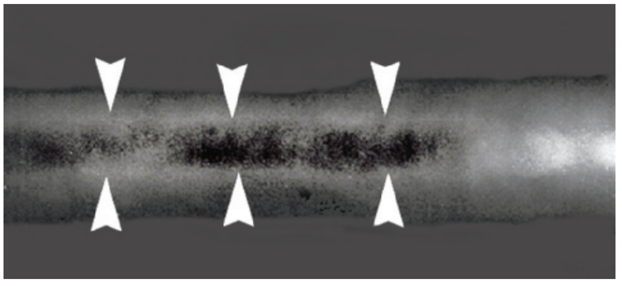
RADIOGRAPHIC IMAGE: A darker density band, with very straight parallel edges, in the center of the width of the weld image.



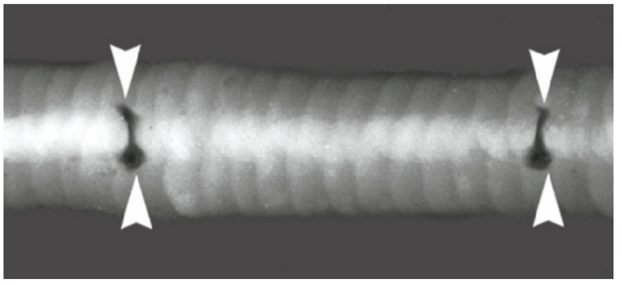
WELDING DEFECT: Internal concavity (suck back). A depression in the center of the surface of the root pass.



WELDING DEFECT: Interpass slag inclusions. Usually nonmetallic impurities that solidified on the weld surface and were not removed between weld passes.

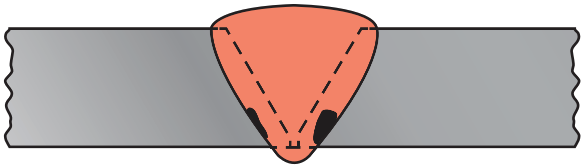


RADIOGRAPHIC IMAGE: An elongated, irregular darker density with fuzzy edges in the center of the width of the weld image.

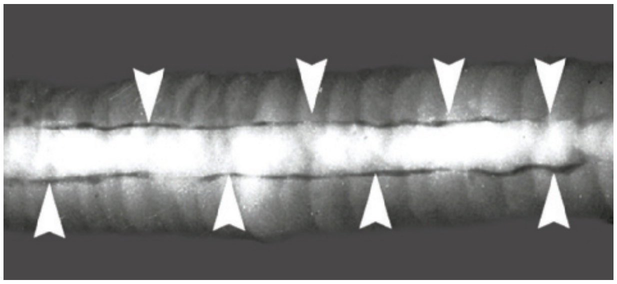


RADIOGRAPHIC IMAGE: An irregularly shaped darker density spot, usually slightly elongated and randomly spaced.

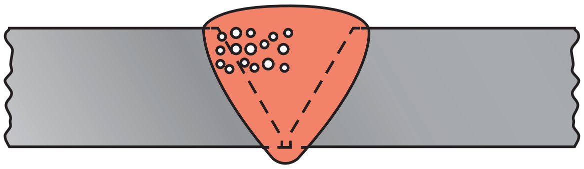
FIGURE 25-38 Welding defects with radiographic images. (*Continued*)



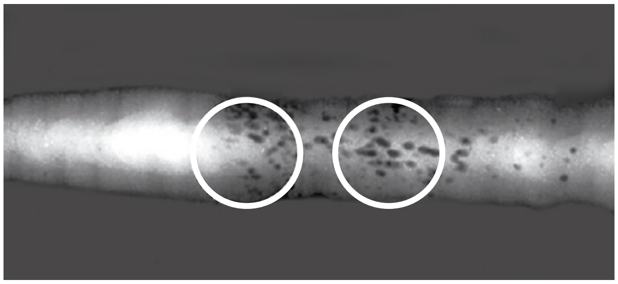
WELDING DEFECT: Elongated slag lines (wagon tracks). Impurities that solidified on the surface after welding and were not removed between passes.



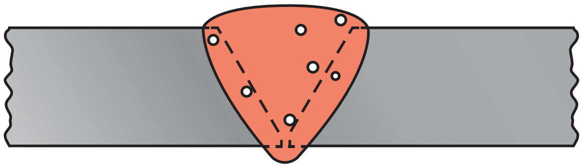
RADIOGRAPHIC IMAGE: Elongated, parallel, or single darker density lines, irregular in width and slightly winding in the length-wise direction.



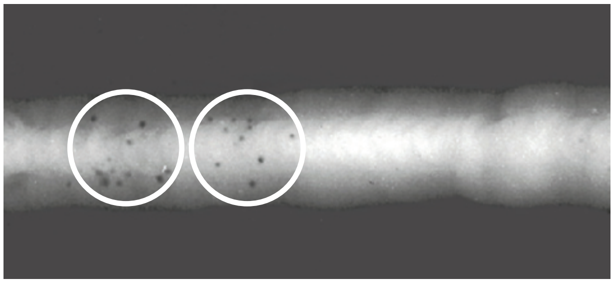
WELDING DEFECT: Cluster porosity. Rounded or slightly elongated voids grouped together.



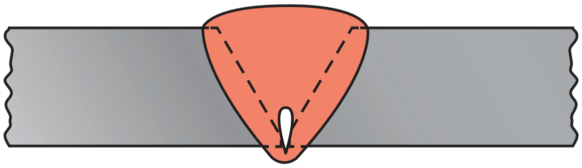
RADIOGRAPHIC IMAGE: Rounded or slightly elongated darker density spots in clusters with the clusters randomly spaced.



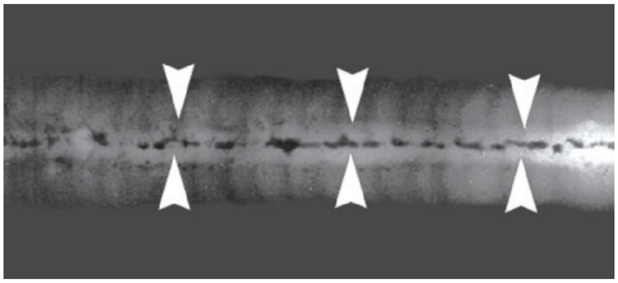
WELDING DEFECT: Scattered porosity. Rounded voids random in size and location.



RADIOGRAPHIC IMAGE: Rounded spots of darker densities random in size and location.

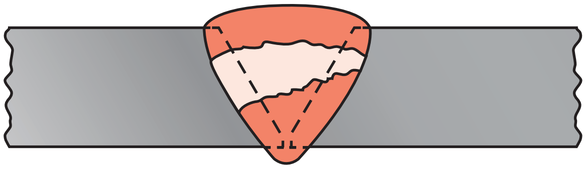


WELDING DEFECT: Root pass aligned porosity. Rounded and elongated voids in the bottom of the weld aligned along the weld centerline.

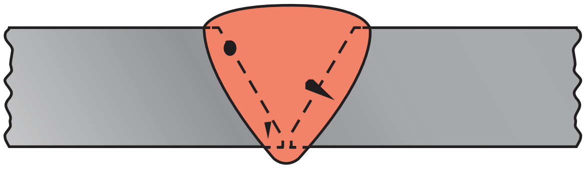


RADIOGRAPHIC IMAGE: Rounded and elongated darker density spots, which may be connected, in a straight line in the center of the width of the weld image.

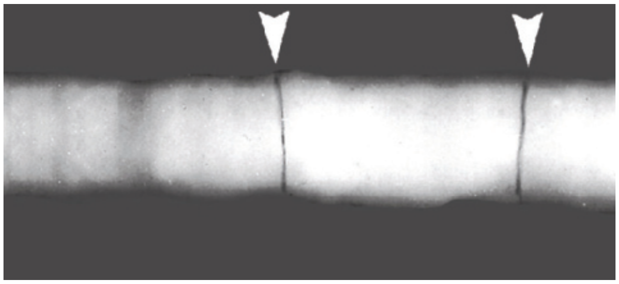
FIGURE 25-38 Welding defects with radiographic images. (*Continued*)



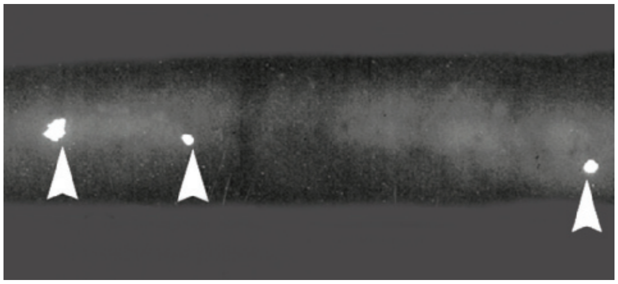
WELDING DEFECT: Transverse crack. A fracture in the weld metal running across the weld.



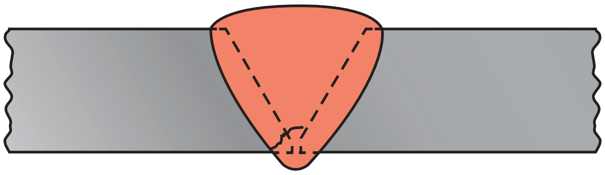
WELDING DEFECT: Tungsten inclusions. Random bits of tungsten fused, but not melted, into the weld metal.



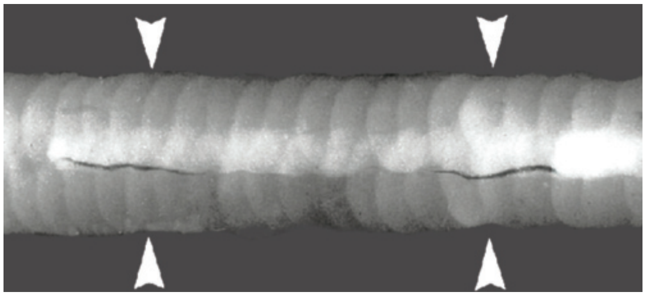
RADIOGRAPHIC IMAGE: Feathery, twisting line of darker density running across the width of the weld image.



RADIOGRAPHIC IMAGE: Irregularly shaped lower density spots randomly located in the weld image.



WELDING DEFECT: Longitudinal root crack. A fracture in the weld metal at the edge of the root pass.



RADIOGRAPHIC IMAGE: Feathery, twisting lines of darker density along the edges of the image of the root pass. The "twisting" feature helps to distinguish the root crack from incomplete root penetration.

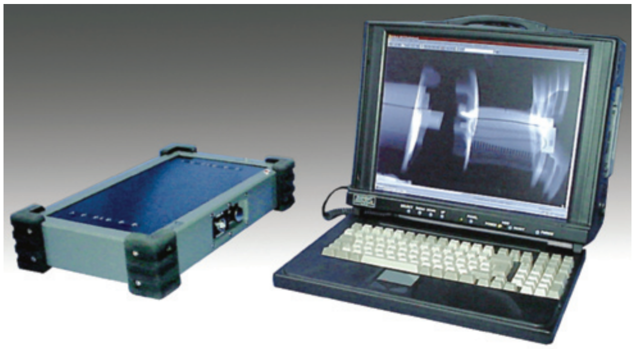
FIGURE 25-38 Welding defects with radiographic images. (*Concluded*)

Leak Checking

Leak checking can be performed by filling the welded container with either a gas or a liquid. There may or may not be additional pressure applied to the material in the weldment. Water is the most frequently used liquid, although sometimes a liquid with a lower viscosity is used. If gas is used, then it may be either a gas that can be detected with an instrument when it escapes through a flaw in the weld or an air leak that is checked with bubbles.

Eddy Current Inspection (ET)

Eddy current inspection (ET) is another nondestructive test. This method is based on magnetic induction in which a magnetic field induces eddy currents within the material being tested. An eddy current is an induced electric current circulating wholly within a mass of metal. This method is effective in testing nonferrous and ferrous materials for internal and external cracks, slag inclusions, porosity, and lack of fusion that are on or very near the



CMOS X-ray

FIGURE 25-39 Mobile X-ray equipment.

CMOS X-ray

FIGURE 25-40 X-raying a weld for quality testing.

Courtesy of Olympus NDT

FIGURE 25-41 Portable ultrasonic inspection unit.

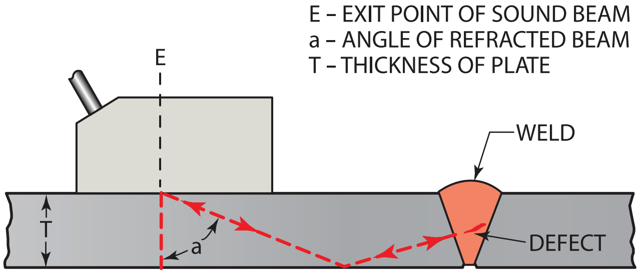


FIGURE 25-42 Ultrasonic testing.

surface. Eddy current cannot locate flaws that are not near the surface.

A coil-carrying high-frequency alternating current is brought close to the metal to be tested. A current is produced in the metal by induction. The part is placed in or near high-frequency alternating-current coils. The magnitude and phase difference of these currents is, in turn, indicated in the actual impedance value of the pickup coil. Careful measurement of this impedance is the revealing factor in detecting defects in the weld.

Hardness Testing

Hardness is the resistance of metal to penetration and is an index of the wear resistance and strength of the metal. Hardness tests can be used to determine the relative hardness of the weld with the base metal. The two types of hardness testing machines in common use are the Rockwell and the Brinell testers.

The **Rockwell hardness tester**, **Figure 25-43**, uses a 120° diamond cone for hard metals and a 1/16-in. (1.58-mm) and 1/8-in. (3.175-mm) diameter hardened steel ball for softer metals. The method is based on resistance-to-penetration measurement. The hardness is read directly from a dial on the tester. The depth of the impression is measured instead of the diameter. The tester has two scales for reading hardness, known as the B-scale and the C-scale. The C-scale is used for harder metals, and the B-scale is used for softer metals.

The **Brinell hardness tester** measures the resistance of material to the penetration of a steel ball under constant pressure (approximately 3000 kg) for a minimum of approximately 30 sec, **Figure 25-44**. The diameter is measured microscopically, and the Brinell number is checked on a standard chart. Brinell hardness numbers are obtained by dividing the applied load by the area of the surface indentation.

Newage Testing Instruments, Inc.

FIGURE 25-43 Rockwell hardness tester.

Newage Testing Instruments, Inc.

FIGURE 25-44 Brinell hardness tester.

Summary

It is impossible to "inspect in" quality; no amount of inspection will produce a quality product. Quality is something that must be built into a product. The purpose of testing and inspection is to verify that welds meet the appropriate code or standard so that they are fit for service. A weld must be able to meet the demands placed on the weldment without failure.

No weld is perfect and codes and standards recognize that fact. Each code or standard will have the acceptance limits for discontinuities. Knowing the cause of weld defects and discontinuities can aid you in producing higher-quality welds by recognizing the cause and effect of such problems. Producing high-quality welds is a matter of skill and knowledge, which you must develop. Good welders often know whether welds they produce will or will not pass inspection as soon as the finished the weld. Inspecting your welds as part of your training program will help you develop this skill.

Review

1. Why are all welds not inspected to the same level or standard?
2. Why is the strength of all production parts not known if a sample number of parts are mechanically tested?
3. Why is it possible to do more than one nondestructive test on a weldment?
4. What is a discontinuity?
5. What is a defect?

6. What is tolerance?
7. What are the 12 most common discontinuities?
8. How can porosity form in a weld and not be seen by the welder?
9. What welding process can cause porosity to form?
10. How is piping porosity formed?
11. What are inclusions, and how are they caused?
12. When does inadequate joint penetration usually become defective?
13. How can a notch cause incomplete fusion?
14. How can an arc strike appear on a guided-bend test?
15. What is overlap?
16. What is undercut?
17. What causes crater cracks?
18. What is underfill?
19. What is the difference between a lamination and a delamination?
20. How can stress be reduced through a plate's thickness to reduce lamellar tearing?
21. What would be the tensile strength in pounds per square inch of a specimen measuring 0.375 in. thick and 1.0 in. wide if it failed at 27,000 lb?
22. What would be the elongation for a specimen for which the original gauge length was 2 in. and final gauge length was 2.5 in.?
23. How are the results of a stress test reported?
24. What would be the transverse shear strength per inch of weld if a specimen that was 2.5 in. wide withstood 25,000 lb?
25. What would be the longitudinal shearing strength per millimeter of a specimen that was 50.8 mm wide and 116 mm long and withstood 23,000 kg/mm?
26. What are the three methods of destructive testing of a welded butt joint?
27. How are the specimens bent for a guided-, root-, face-, and side-bend test?
28. How wide should a specimen be if the material thickness is
    a. 0.375 in.?
    b. 6.35 mm?
29. Why are guidelines drawn on the surface of a free-bend specimen?
30. What part of a fillet weld break test is examined?
31. What can happen if acids are handled carelessly?
32. What information about the weld does an impact test provide?
33. Which nondestructive test is most commonly used?
34. List the five steps to be followed when using a penetrant test.
35. What properties must metal have before it can be tested with the MT process?
36. Why will some flaws appear larger on an X-ray than they are in the weld?
37. How is the size of a flaw determined using ultrasonic inspection?
38. What is the major limitation of eddy current inspection?
39. What information does a hardness test reveal?
40. Why is it important to select the correct welding code or standard?

Chapter 26
Welding Metallurgy

OBJECTIVES

After completing this chapter, the student should be able to

- list the crystalline structures of metals and explain how grains form.
- work with phase diagrams.
- list the five mechanisms used to strengthen metals.
- explain why steels are such versatile materials.
- describe the types of weld heat-affected zones.
- discuss the problems hydrogen causes during steel welding.
- discuss the heat treatments used in welding.
- explain the cause of corrosion in stainless steel welds.

KEY TERMS

acicular (needle-like) structure
allotropic
allotropic transformation
austenite
body-centered cubic (BCC)
cementite
crystal lattices
crystalline structures
eutectic composition
face-centered cubic (FCC)
ferrite
grain refinement
heat-affected zone (HAZ)
heat treatments
martensite
metallurgy
pearlite
phase diagrams
precipitation hardening
recrystallization temperature
solid solutions
spheroidized microstructure
tempering
unit cell

INTRODUCTION

To consistently deposit uniform, high-quality welds, skilled welders need to know more than just how to establish an arc and manipulate the electrode. It is important for a competent welder to understand the materials being welded. With this knowledge, the welder can select the best processes and procedures to produce a weldment that is as strong and tough as possible. The welder needs to learn **metallurgy** to recognize that special attention might be needed when welding certain types of steel and to understand the kind of care required.

Metals gain their desirable mechanical and chemical properties as a result of how they are shaped or formed, their alloying elements, and how they were heat-treated. Welding operations heat the metals, and that heating will certainly change not only the metal's initial structure but also its properties. A skilled welder can minimize the effects these changes will have on the metal and its properties.

HEAT, TEMPERATURE, AND ENERGY

Heat and *temperature* are both terms used to describe the quantity and level of thermal energy present. To better comprehend what takes place during a weld, you must understand the differences between heat and temperature. Heat is the quantity of thermal energy and temperature is the level of thermal activity.

Although both *heat* and *temperature* are used to describe the thermal energy in a material, they are independent values. A material can have a large quantity of heat energy in it, but the material can be at a low temperature. Conversely, a material can be at a high temperature but have very little heat.

Heat

Heat is the amount of thermal energy in matter. All matter contains heat down to absolute zero (−460°F or −273°C). The basic U.S. unit of measure for heat is the British thermal unit (BTU). One BTU is defined as the amount of heat required to raise 1 pound of water 1 degree Fahrenheit, and the SI unit of heat is the joule (J).

There are two forms of heat. One is called *sensible* because, as it changes, a change in temperature can be sensed or measured. The other form of heat is called *latent*. Latent heat is the heat required to change matter from one state to another, and it does not result in a temperature change. For example, if a pot containing water is heated on a stove, then the water picks up heat from the burner and the water's temperature increases. The more heat put into the water, the higher its temperature and the greater its sensible heat until it begins to boil. Once the water reaches 212°F (100°C), its temperature stops rising. As long as the pot is on the burner, heat is being put into the water, but there is no increase in its sensible heat because its temperature did not increase. The heat is all going into the latent heat required to change the water from the liquid state to a gaseous state, **Figure 26-1**.

Latent heat is absorbed by a material as it changes from a solid to a liquid state and from a liquid to a gaseous state. When matter changes from a gaseous to a liquid state or from a liquid to a solid state, latent heat must be removed, **Figure 26-2**. A change in a material's latent heat also occurs when there is a change in the structure of the material. For example, when the crystal lattice of a metal changes, a change in latent heat occurs.

EXPERIMENT 26-1

Latent and Sensible Heat

In this experiment you will be working in a small group to observe latent and sensible heat. Using two beakers, two

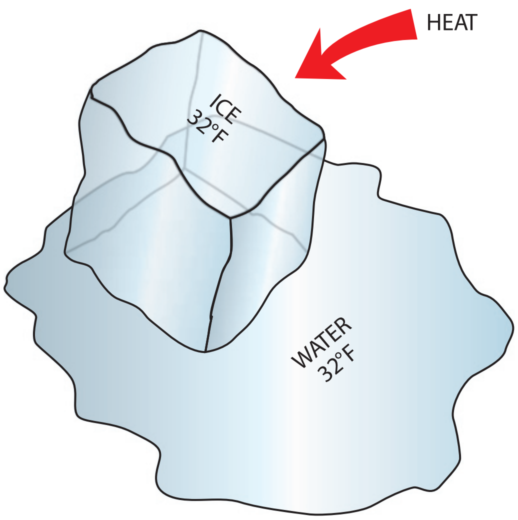


FIGURE 26-1 There is no change in temperature when there is a change in state.

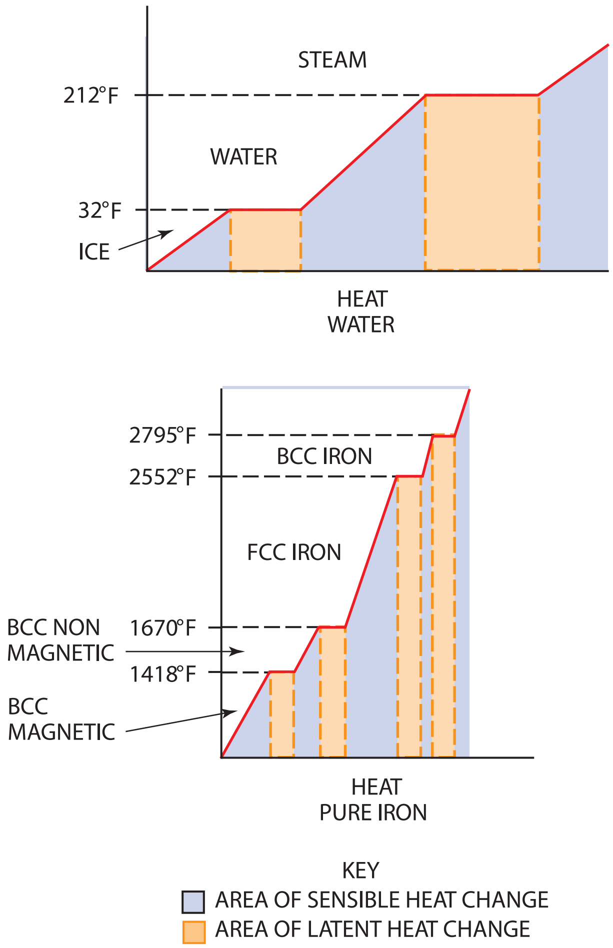


FIGURE 26-2 Sensible and latent heat.

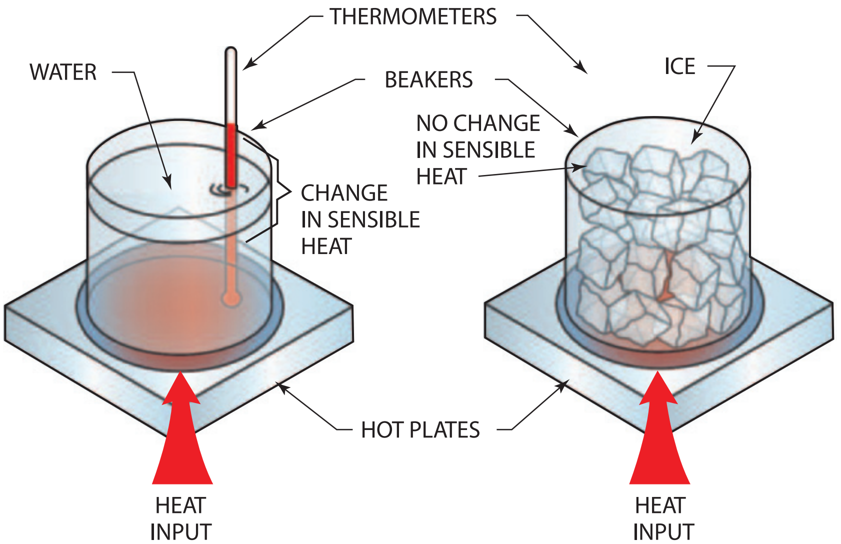


FIGURE 26-3 Both beakers have heat being added, but only one has a change in temperature.

hot plates, two thermometers, a cup of ice, a cup of ice water, gloves, safety glasses, and any other required safety protection, you are going to observe the effect of latent heat on the temperature increase of water, **Figure 26-3**.

Put 1 cup of ice water 32°F (0°C) in one beaker and 1 cup of ice 32°F (0°C) in the other beaker. Place both beakers on a hot plate. Slowly stir the contents of each beaker using the thermometers. Observe the change in temperatures each thermometer measures. Record the following information:

1. What was the temperature when you started?
2. What was the temperature after 1 minute?
3. What was the temperature of the water without the ice when the ice in the other cup was all gone?
4. How long did it take for all of the ice to melt?

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

TEMPERATURE

Temperature is a measurement of the vibrating speed or frequency of the atoms in matter. The atoms in all matter vibrate down to absolute zero. The basic unit of measure is the degree. The U.S. unit is degrees Fahrenheit, and the SI unit is degrees Celsius.

As matter becomes warmer, its atoms vibrate at a higher frequency. As matter cools, the vibrating frequency slows. This vibration of the atoms is what gives off the infrared light that comes from all objects that are above absolute zero. When the object becomes hot enough, the vibrating frequency of the atoms gives off visible light. We see that light as a dull red glow when the surface reaches a little above 1000°F. As the surface becomes even hotter, we can see the color light that it gives off change until it glows "white hot," **Figure 26-4**.

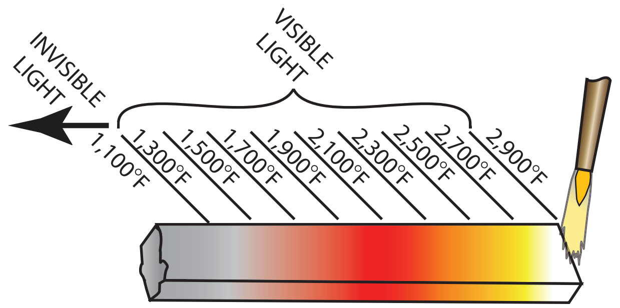


FIGURE 26-4 Visible and invisible light.

We can tell the temperature of an object by the frequency of the light that its vibrating atoms produce. That is how scientists tell the temperature of distant stars.

EXPERIMENT 26-2

Temper Colors

In this experiment you will be working in a small group to observe the formation of temper colors as metal is heated. Using a piece of mild steel that has been ground off to a bright clean mill scale–free surface, a safely set-up oxyfuel torch, gloves, safety glasses, and required personal protection, you are going to observe the changing temperature's effect on the color of the steel, **Figure 26-5**.

Light the torch and hold it near one side of the mild steel. Observe the other side of the metal to see when it begins to change color. Record the following information:

1. What was the first color that you could see?
2. What were the second, third, fourth, and so on, colors that you could see?

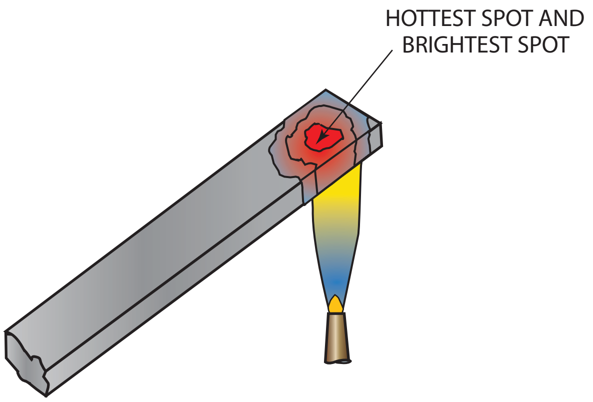


FIGURE 26-5 As the temperature of the metal increases it begins to glow.

3. What was the last color that appeared before the metal melted?
4. Compare the colors you saw with the colors and temperatures shown in **Figure 26-6**.

Repeat this experiment using different metals and see what colors they produce.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRODUCTION OF METALS

In learning welding skills, an understanding of the mechanical properties of metals is most important. The mechanical properties of a metal can be described as those quantifiable properties that enable the metal to resist externally imposed forces without failing. If the mechanical properties of a metal are known, then a product can be constructed that will meet specific engineering specifications. As a result, a safe and sound structure can be constructed.

Steel Making

Casting, rolling, and forging each affect the grain structure of metals in their own unique way. The mechanical properties resulting from the changes they cause in the metal's grain structure give metals some unique properties. These properties are similar in each and every type of metal product they are used to form. All thermal processes including welding affect the original grain structure of metals. Because steel is the most commonly welded product, and because welding on it affects the grain structure similarly to other metals, it will be used as an example in the following description of forming metal into usable products.

NOTE

Recycling of metals has resulted in a significant increase in the use of scrap metal for metal production; however, raw ore is still used for the majority of metal production.

Iron Ore

Steel making begins with the mining of the ore. The ore is then crushed and, along with fluxing agents and possibly some alloys, is loaded into a blast furnace. The furnaces may be heated with electricity, coal, coke, or other fuel. As the mixture melts, the fluxes combine with the ore to separate the metal from impurities in the mixture. The impurities that have combined with flux form a slag that floats to the surface of the molten metal. After analyzing the chemical composition of the molten metal, alloying elements may be added to create the desired type or grade of metal.

NOTE

This process is very similar to what takes place during all welding processes that have fluxes combined with a filler metal.

TEMPERATURE	TEMPER COLOR	
800°F (427°C)	Dark Gray	
560°F (293°C)	Blue	
540°F (282°C)	Full Purple	
520°F (271°C)	Brown Purple	
500°F (260°C)	Brown Yellow	
490°F 254°C)	Yellow Brown	
470°F (243°C)	Dark Straw	
440°F (227°C)	Light Straw	
430°F (221°C)	Faint Straw	

FIGURE 26-6 Temper colors.

Once the metal has been purified in the furnace, it is transferred to a ladle so it can be transported to the metal forming area. Two interim processes, casting ingots and continuous casting, are commonly used to transform the molten metal into a form that can then be processed into usable products.

Ingot Casting

Ingot casting has been around since antiquity. In this process the molten metal is poured into large molds where it is allowed to cool and solidify into block shapes called ingots. The ingots are then placed in a furnace where they are slowly reheated so that the temperature across the entire ingot is the same. The temperature across the ingot must be the same because if the temperature is hotter in the center, then it will be squeezed out like the soft filling in a doughnut during the forming process.

Once the ingots' internal temperatures are normalized, they are sent to the forming mill where they can be rolled, extruded, or drawn into their final shapes.

Continuous Casting

Continuous casting is a much more recent process. Continuous casting is the most efficient way that molten steel is initially formed into a shape that can be formed into a finished product. In the continuous casting process, molten steel flows out of the bottom of a ladle into a tundish, **Figure 26-7**. Most of the impurities and slag float on top of the molten steel in the ladle, so the steel pouring out of the bottom hole is relatively pure. From the tundish, the molten steel flows into a water-cooled mold where it is shaped into a square. The mold cools the outside of the steel to a pliable solid, but the center still remains liquid. With additional cooling, the entire section solidifies.

As the steel cools to a solid, any impurities such as slag and gas bubbles (porosity) are forced to the center of the cooling steel, much like air bubbles are forced to the center of an ice cube. Once the steel has cooled to a point where it will hold its shape, it passes across a set of rollers that guide it to a station where it is cut into slabs.

The slabs are allowed to cool so that the internal temperature can be normalized before they are fed into the forming mill.

Metal Forming

Forming mills are used to convert the ingots into usable products like plates, sheets, pipe, rods, and wire. Forming mills can process the ingots by rolling, drawing, or extruding them into their final shape. In the forming process the

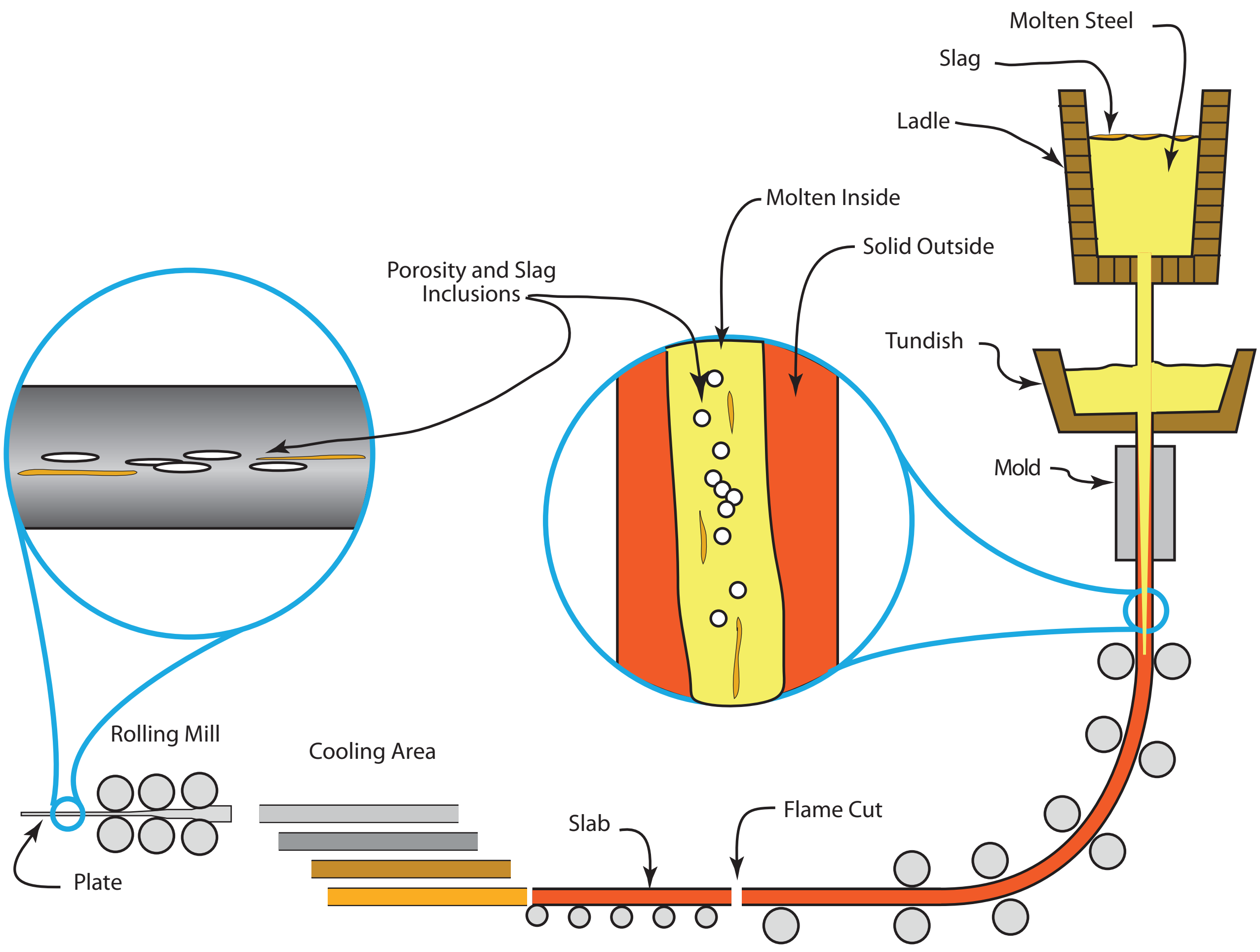


FIGURE 26-7 Continuous casting.

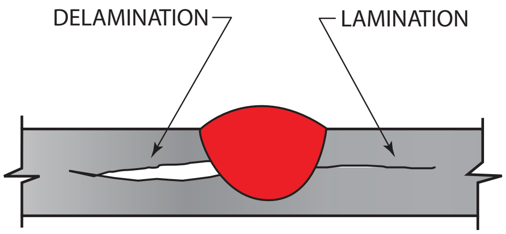


FIGURE 26-8 Lamination and delamination.

impurities in the ingots are squeezed smaller and smaller but remain near the center of the finished shape. Sometimes larger areas of impurities can form a layer within the finished plate called a lamination. If the lamination separates, it is called a delamination, **Figure 26-8**.

> **NOTE**
>
> All metals will have some degree of dissolved gasses and slag that have been factored into their strength rating.

Grain Structure

The size and shape of every type of metal's grain structure are the result of the process that was used to form its shape—casting, rolling, drawing, extruding, or forging.

Cast Grain Structure Casting grains form as the outside of the molten metal begins to cool. The individual grains grow toward the center of the casting, **Figure 26-9A**. As the grain structure grows inward, impurities in the metal are pushed into the center of the casting. The grain structure of some castings becomes so large that it can easily be seen on the broken surface.

Rolled Grain Structure Rolling, drawing, and extruding all cause the cast grain structure to be flattened and elongated as a result of the forces applied by the rollers, **Figure 26-9B**. This grain structure is strongest in the direction it was rolled.

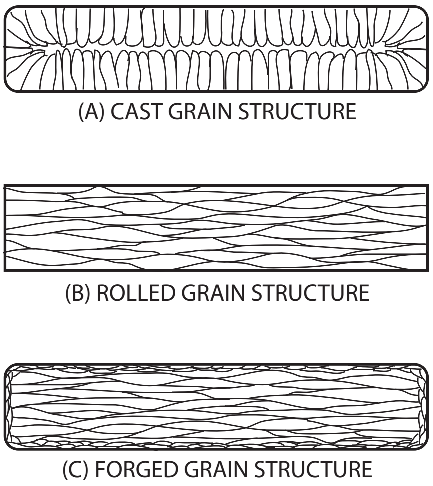


FIGURE 26-9 Grain structures.

The breaking down of the cast grain structure is called refining the grain, and grain refinement strengthens the metal. If the final rolling is performed on the plate after it cools, then even more grain refinement occurs, resulting in a higher strength and hardness. These sheets are called cold rolled and have a smoother surface than do the hot rolled sheets.

Forging Grain Structure Forging causes the cast or rolled grain structures to be broken down even further in a layer around the blank material used for the forging, **Figure 26-9C**. The forging process results in a strong, hard layer of fine grain structure surrounding the core grain structure.

> **NOTE**
>
> In a localized area, welding destroys the grain structure formed during the production of the metal. The molten metal cools to form a cast grain structure, and the welding heat also transforms the surrounding area's grain structure.

MECHANICAL PROPERTIES

All of a metal's properties interact with one another. Some properties are similar and complement each other, but others tend to be opposites. For example, a metal cannot be both hard and ductile. Some metals are hard and brittle, and others are hard and tough. Probably the most outstanding property of metals is the ability to have their properties altered by some form of heat treatment. Heat treatment alters the grain structure in a metal that was created by the forming process. Metals can be soft and then made hard, brittle, or strong by the correct heat treatment, yet other heat treatments can return the metal back to its original, soft form.

It is the responsibility of the metallurgist or engineer to select a metal that has the best group of properties for any specific job. Except in very unusual cases, a metallurgist would not create a new alloy for a job but would merely select one from the tens of thousands of metal alloys already available. Often metallurgists must make difficult choices when designs call for properties that are usually not found together. Additionally, the more unique the alloy, the greater its cost and often the more difficult it is to weld.

This section describes some of the significant mechanical properties of metals. The next section describes how various heat treatments can be used to change a metal's properties.

The sections that follow describe some of the significant mechanical properties that the welder should be familiar with to do a successful job of welding fabrication.

Hardness

Hardness may be defined as resistance to penetration. Files and drills are made of metals that rank high in hardness when properly heat-treated. The hardness property may, in many metals, be increased or decreased by heat-treating methods and increased in other metals by cold working.

Because hardness is proportional to strength, it is a quick way to determine strength. It is also useful in determining whether the metal received the proper heat treatment, because heat treatment also affects strength. Hardness is measurable in a number of ways. Most methods quantify a metal's resistance to highly localized deformation.

Brittleness

Brittleness is the ease with which a metal will crack or break apart without noticeable deformation. Glass is brittle; when broken, all of the pieces fit back together because it did not bend (deform) before breaking. Some types of cast iron are brittle and once broken will fit back together like a puzzle's parts. Brittleness is related to hardness in metals. Generally, as the hardness of a metal is increased, the brittleness is also increased. Brittleness is not measured by any testing method. It is the absence of ductility.

Ductility

Ductility is the ability of a metal to be permanently twisted, drawn out, bent, or changed in shape without cracking or breaking. Ductile metals include aluminum, copper, zinc, and soft steel. Ductility is measurable in a number of ways. Ductility in tensile tests is usually measured as a percentage of elongation and as a percentage of reduction in area. It also can be measured with bend tests.

Toughness

Toughness is the property that allows a metal to withstand forces, sudden shock, or bends without fracturing. Toughness may vary considerably with different methods of load application and is commonly recognized as resistance to shock or impact loading.

Toughness is measured most often with the Charpy test. This test yields information about the resistance of a metal to sudden loading in the presence of a severe notch. Because only a small specimen is required, the test is faulted for not providing a general picture of a component's toughness. Unfortunately, tests on a larger scale require very expensive equipment and are very time-consuming.

Strength

Strength is the property of a metal to resist deformation. Common types of strength measurements are tensile, compressive, shear, and torsional, **Figure 26-10**.

- **Tensile strength:** *Tensile strength* refers to the property of a material that resists forces applied to pull metal apart. Tension has two parts: yield strength and ultimate strength. *Yield strength* is the amount of strain needed to permanently deform a test specimen. The *yield point* is the point during tensile loading when the metal stops stretching and begins to be permanently made longer by deforming. Like a rubber band that stretches and returns to its original size, metal that stretches before the yield point is reached will return to its original shape. After the yield point is reached, the metal is usually longer and thinner. Some metals stretch a great deal before they yield, and others stretch a great deal before and after the yield point. These metals are considered to have high ductility. *Ultimate strength* is a measure of the load that breaks a specimen. Some metals may become work-hardened as they are stretched during a tensile test. These metals will actually become stronger and harder as a result of being tested. Other metals lose strength once they pass the yield point and fail at a much lower force. Metals that do not

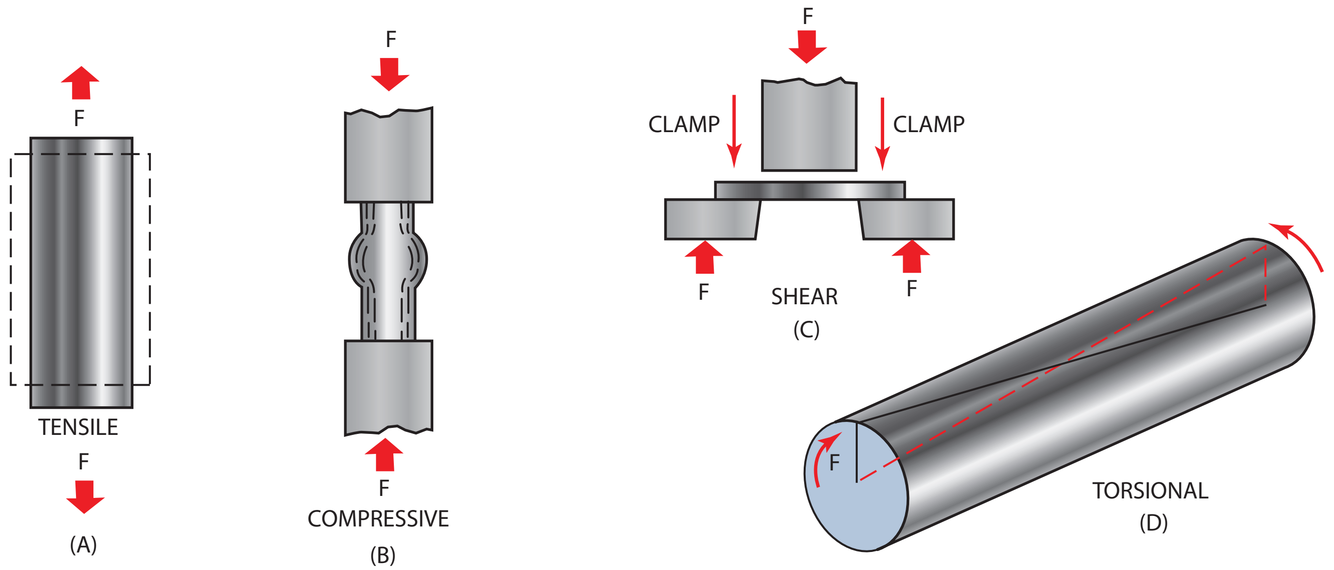


FIGURE 26-10 Types of forces (F) applied to metal.

stretch much before they break are brittle. The tensile strength of a metal can be determined by a tensile testing machine.

- **Compressive strength:** Compressive strength is the property of a material to resist being crushed. The compressive strength of cast iron, rather brittle material, is three- to four-times its tensile strength.
- **Shear strength:** Shear strength of a material is a measure of how well a part can withstand forces acting to cut or slice it apart.
- **Torsional strength:** Torsional strength is the property of a material to withstand a twisting force.

Other Mechanical Properties

Strain is deformation caused by stress. The part shown in **Figure 26-11** is under stress and was strained (deformed) by the external load. The deformation is in the form of a bend.

Elasticity is the ability of a material to return to its original form after removal of the load. The yield point of a material is the limit to which the material can be loaded and still return to its original form after the load has been removed, **Figure 26-12**.

Elastic limit is defined as the maximum load, per unit of area, to which a material will respond with a deformation directly proportional to the load. When the force on the material exceeds the elastic limit, the material will be deformed permanently. The amount of permanent deformation is proportional to the stress level above the elastic limit. When stressed below its elastic limit, the metal returns to its original shape.

Impact strength is the ability of a metal to resist fracture under a sudden load. An example of a material that is ductile and yet has low impact strength is Silly Putty®. If it is pulled slowly, then it stretches easily; if it is pulled quickly, then it forms a brittle fracture.

STRUCTURE OF SOLID MATTER

All solid matter exists in one of two basic forms. Solid matter is either crystalline or amorphic in form. Solids that are crystalline in form have an orderly arrangement of their atoms. Each crystal making up the solid can be very small, too small to be seen without a microscope. Examples of materials that are crystalline in form include metals and most minerals, such as table salt, **Table 26-1**. Amorphic materials have no orderly arrangement of their atoms into crystals. Examples of amorphic materials include glass and silicon, **Table 26-2**. Both crystalline and amorphic materials look and feel like solids, so without sophisticated testing equipment you cannot tell the difference between them.

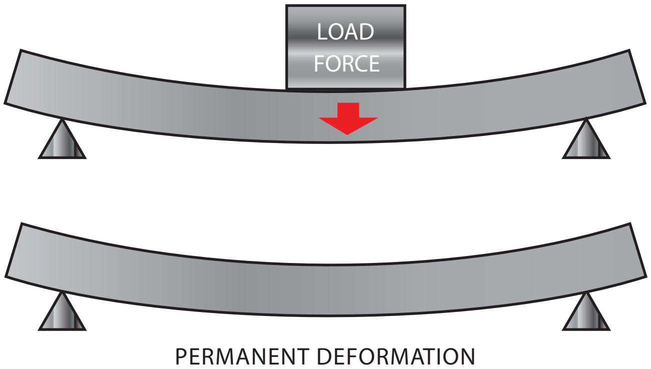


FIGURE 26-11 Effect of excessive stress causing permanent strain in a beam.

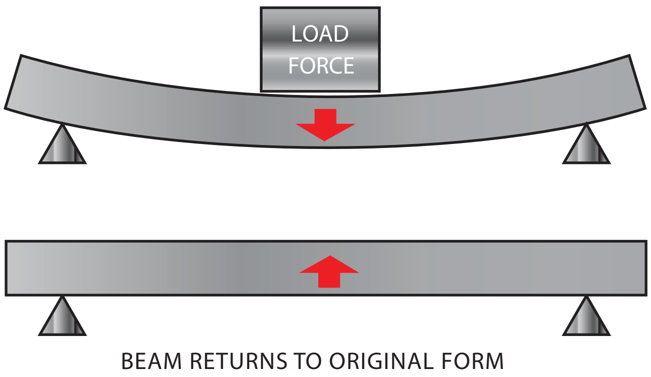


FIGURE 26-12 Reaction of an elastic beam to a force.

Metal	Crystal Type
Aluminum	fcc
Chromium	bcc
Copper	fcc
Gold	fcc
Iron (alpha)	fcc
Iron (delta)	bcc
Iron (gamma)	fcc
Lead	fcc
Nickel	fcc
Silver	fcc
Tungsten	bcc
Zinc	hcp

KEY
fcc = Face-centered cubic
bcc = Body-centered cubic
hcp = Hexagonal close-packed

TABLE 26-1 Crystal Structure of Common Metals

Materials	Compound	Crystal Type
Copper acetylide	Cu_2C_2	None
Gadolinium oxide	Gd_2O_3	None
Iron hydroxide	$Fe(OH)_2$	None
Lead oxide	Pb_2O	None
Nickel monosulfide	NiS	None
Silicone dioxide	SiO_2	None

TABLE 26-2 Amorphic Materials

Crystalline Structures of Metal

The fundamental building blocks of all metals are atoms arranged in very precise three-dimensional patterns called **crystal lattices**. Each metal has a characteristic pattern that forms these crystal lattices. The smallest identifiable group of atoms is the **unit cell**. The unit cells that characterize all commercial metals are illustrated in **Figure 26-13**, **Figure 26-14**, and **Figure 26-15**. It may take millions of these individual unit cells to form one crystal. Although some metals have identical atomic arrangements, the dimensions between individual atoms vary from metal to metal. Some metals change their lattice structure when heated above a specific temperature.

Crystals Develop and Grow Crystals grow by the attachment of atoms to the submicroscopic unit cells forming the metal's characteristic crystal structure. The final individual crystal size within the metal depends on the length of time the material is at the crystal-forming temperature and any obstructions to its growth. In most cases, solid crystals continue to grow larger randomly from a liquid as it cools until they encounter other crystals growing in a similar fashion. The result is solid metal composed of microscopic crystals with the same structure but different orientations. Their crystalline shapes depend on how they grew and how other crystals interrupted that growth. Crystals growing from liquid develop a dendritic or columnar structure, **Figure 26-16** and **Figure 26-17**.

The crystal structures are studied by polishing small pieces of the metals, etching them in dilute acids, and examining the etched structures with a microscope. Such examinations enable metallurgists to determine how the metal formed and to observe changes caused by heat treating and alloying. These microscopic examinations reveal various combinations of three different phases: pure metal, **solid solutions** of two or more metals dissolved in one another, and intermetallic compounds.

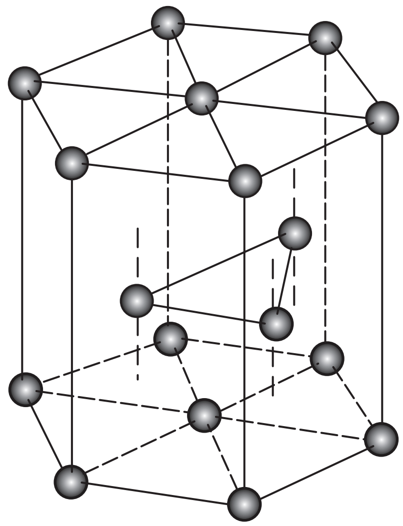


FIGURE 26-15 Hexagonal close-packed cubic unit cell.

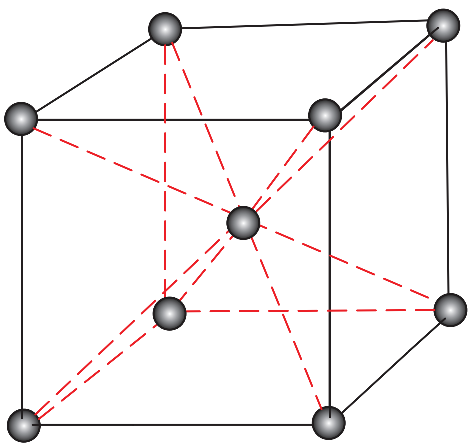


FIGURE 26-13 Body-centered cubic unit cell.

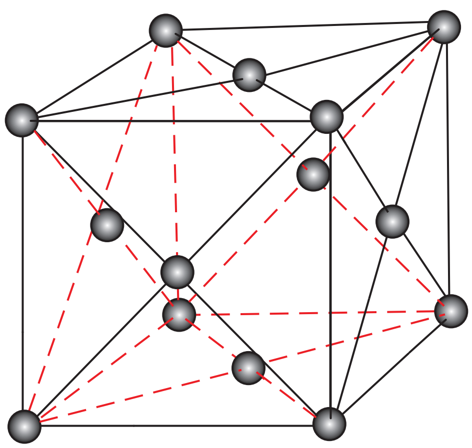
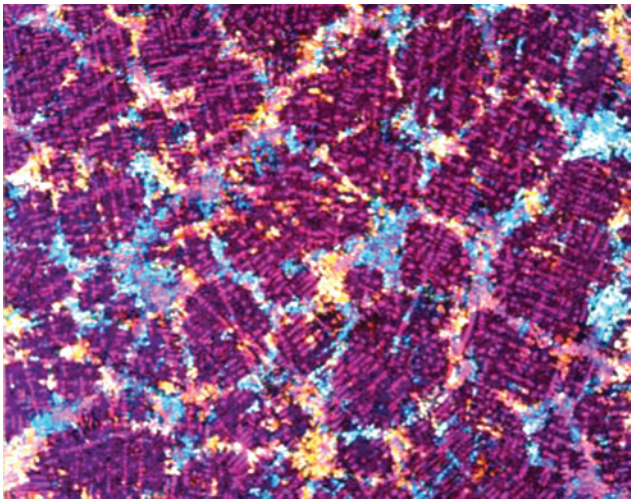


FIGURE 26-14 Face-centered cubic unit cell.



Photograph courtesy of Buehler

FIGURE 26-16 Cell boundaries in gray cast iron.

FIGURE 26-17 Columnar structure.

PHASE DIAGRAMS

If the metalworking industries used only pure metals, then the only required information about their crystalline structure could be a list of their melting temperatures and **crystalline structures**. However, most engineering materials are alloys, not pure metals. An *alloy* is a metal with one or more elements added to it, resulting in a significant change in the metal's properties. It is inconvenient, if not impossible, to list all phases and temperatures at which alloys exist. That kind of information is summarized in graphs called **phase diagrams**. Phase diagrams are also known as *equilibrium* or *constitution diagrams*, and the terms are used interchangeably. These diagrams do not necessarily describe what happens with rapid changes in temperature because metals are sluggish in response to temperature fluctuations. They do describe the constituents present at temperature equilibrium.

Lead-Tin Phase Diagram

The chart in **Figure 26-18** is a phase diagram representing the changes brought about by alloying lead (Pb) with tin (Sn). Although this phase diagram is simpler than the iron-carbon phase diagram used for steel, it has many similarities. On the charts, temperature is vertical and alloy is percent; in this case, lead and tin are horizontal.

Metallurgy uses Greek letters to identify different crystal structures. On this chart, the Greek letter "a" (alpha, or α) is used for one crystal form and the Greek letter "b" (beta, or β) is used to represent the other crystal form. The chart has four different areas identified:

1. *Liquid phase:* The area at the top with the highest temperatures is where all the metal is a molten liquid.
2. *Solid phase:* The area in the lower center with the lowest temperatures is a solid mixture of α- and β-type crystals.
3. *Liquid-solid phase:* The two triangular areas that touch in the center contain a paste or slurry made up of liquid and a specific type of solid crystals.
4. *Solid-solution phase:* The two triangular areas that stand vertical, one on each side next to the temperature scales, are solid crystals in either the α form on the left side or the β form on the right side.

Notice on the chart that although 100% lead becomes a liquid at 620°F (327°C) and 100% tin becomes a liquid at 420°F (232°C), a mixture of 38.1% lead and 61.9% tin becomes a liquid at 362°F (183°C). The mixture has a lower melting temperature than either of the two metals in the mixture. The mixture melts at a temperature of 258°F (144°C) below 100% lead and 58°F (49°C) below

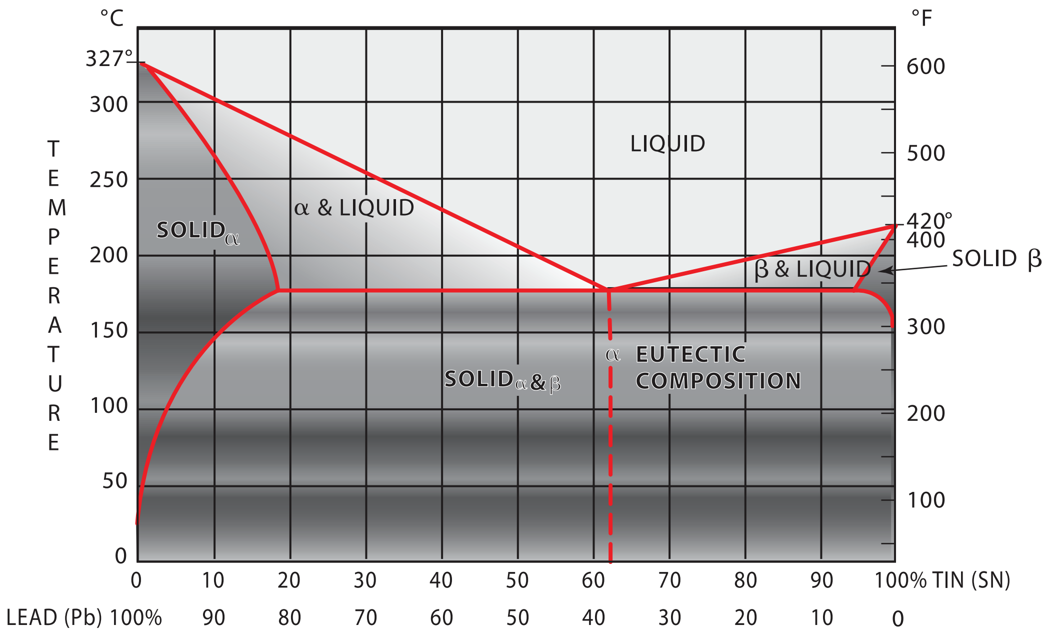


FIGURE 26-18 Lead-tin phase diagram.

100% tin. This mixture is called the eutectic composition of lead and tin. A **eutectic composition** is the lowest possible melting temperature of an alloy.

On the chart, the broadest temperature for a slurry or paste is a mixture of approximately 80% (80.5%) lead and 20% (19.5%) tin. This mixture remains partially liquid and solid during a 173°F (78°C) temperature change. While a metal is in the liquid-solid phase, it is very weak and any movement will cause cracks to form. For this reason, some aluminum alloys crack when a GTA weld is made without adding filler metal and many other metals form crater cracks at the end of a weld. In both cases, as the metal cools it shrinks and pulls itself apart in the center of the weld. The addition of filler metal changes the alloy so it is not as subjective to hot cracking. The only metals that do not go through the liquid-solid phase are pure metals and those eutectic composition alloys.

As a 90% lead and 10% tin mixture cools from the 100% liquid phase, it forms the α solid crystal in a liquid. As cooling continues, all of the liquid forms into the α crystal. But as solid β crystals cool to approximately 300°F (150°C), some of them change into the β crystal form. This type of solid-solution phase change occurs in many metals. Steel goes through several such changes as it is heated and cooled even though it never melted. It is these changes in steel that allow it to be hardened and softened by heating, *quenching*, *tempering*, and *annealing*.

Phase diagrams for other metal alloys are more complicated, but they are used in exactly the same way. They describe the effects of changes in temperature or alloying on different phases.

NOTE

The following text relates to the graph portion of the iron-carbon phase diagram shown in Figure 26-19.

IRON-CARBON PHASE DIAGRAM

The iron-carbon phase diagram is illustrated in **Figure 26-19**. The iron-carbon phase diagram is more complex than that for the lead-tin—it has more lines with more solid-solution phase changes—but it is read in the same way. In the iron-carbon diagram used here, the percentage of iron starts at 100% and goes down to 99.1%, whereas the percentage of carbon goes from 0.0% to 0.9%. Unlike the lead-tin alloys that go from 0.0% to 100% mixtures, very small changes in the percentage of carbon produce major changes in the alloy's properties.

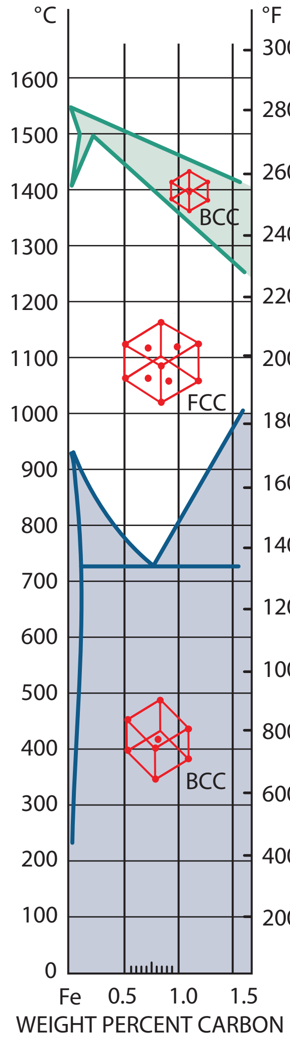


FIGURE 26-19 Iron iron-carbon phase diagram.

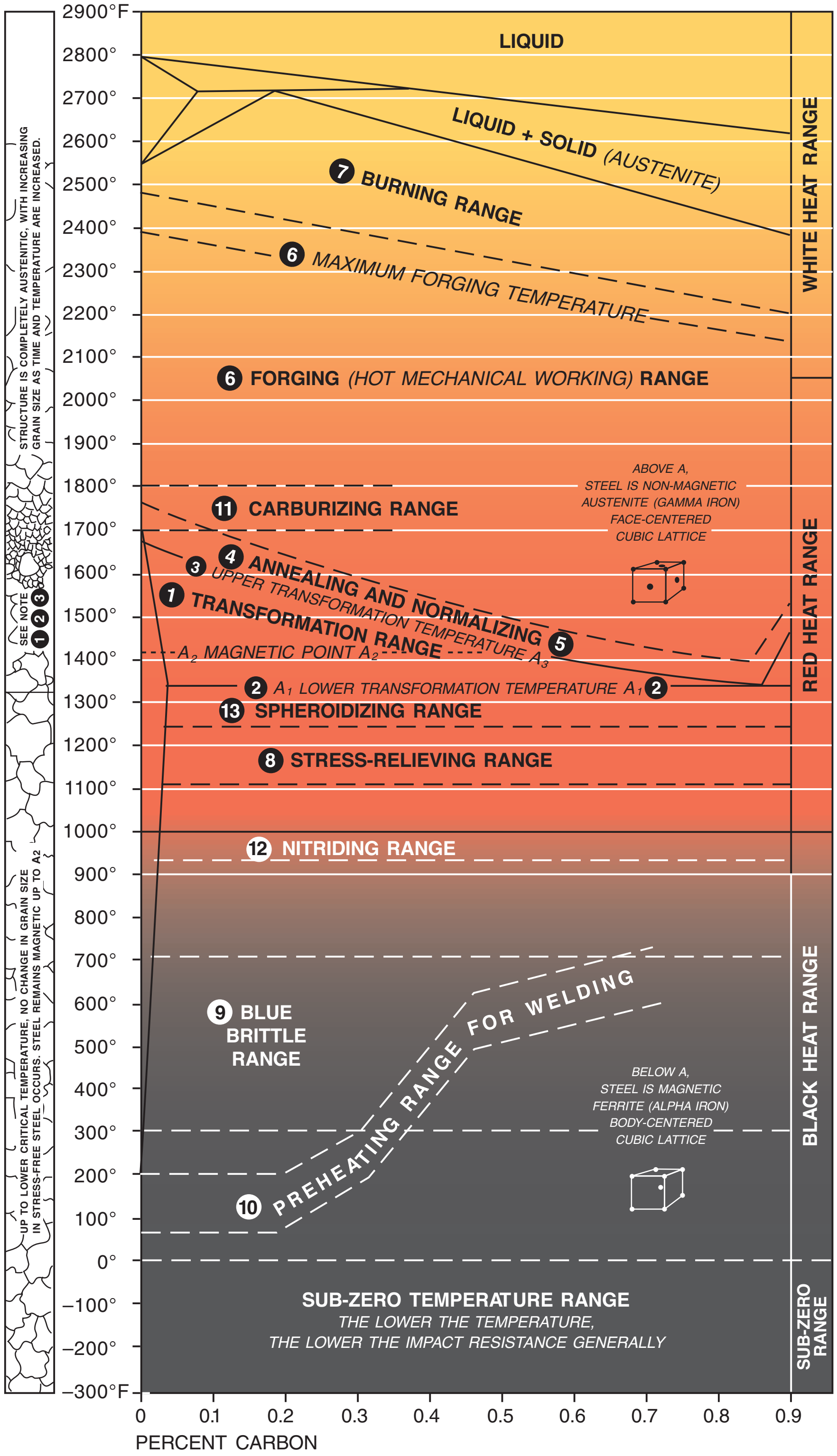
Iron is a pure metal element containing no measurable carbon and is relatively soft. This soft metal when alloyed with as little as 0.80% carbon can become tool steel, **Table 26-3**. Other alloying elements are added to iron to enhance its properties. No other alloying element has such a dramatic effect as carbon.

Iron is called an **allotropic** metal because it exists in two different crystal forms in the solid state. It changes between the different crystal forms as its temperature changes. The changes in the crystal structure occur at very precise

Alloy Name	% Carbon*	Major Properties
Iron	0.0 to 0.03	Soft, easily formed, not hardenable
Low carbon	0.03 to 0.30	Strong, formable
Medium carbon	0.30 to 0.50	High strength, tough
High carbon	0.50 to 0.90	Hard, tough
Tool steel	0.80 to 1.50	Hard, brittle
Cast iron	2 to 4	Hard, brittle, most types resist oxidation

*Carbon is not the only alloying element added to iron.

TABLE 26-3 Iron-Carbon Alloys.



1 TRANSFORMATION RANGE. In this range steels undergo internal atomic changes which radically affect the properties of the material.

2 LOWER TRANSFORMATION TEMPERATURE (A_1). Termed Ac_1 on heating, Ar_1 on cooling. Below Ac_1 structure ordinarily consists of FERRITE and PEARLITE (see below). On heating through Ac_1 these constituents begin to dissolve in each other to form AUSTENITE (see below) which is non-magnetic. This dissolving action continues on heating through the TRANSFORMATION RANGE until the solid solution is complete at the upper transformation temperature.

3 UPPER TRANSFORMATION TEMPERATURE (A_3). Termed Ac_3 on heating, Ar_3 on cooling. Above this temperature the structure consists wholly of AUSTENITE which coarsens with increasing time and temperature. Upper transformation temperature is lowered as carbon increases to 0.85% (eutectoid point).

•FERRITE is practically pure iron (in plain carbon steels) existing below the lower transformation temperature. It is magnetic and has very slight solid solubility for carbon.

• PEARLITE is a mechanical mixture of FERRITE and CEMENTITE.

• CEMENTITE or IRON CARBIDE is a compound of iron and carbon, Fe_3C.

• AUSTENITE is the non-magnetic form of iron and has the power to dissolve carbon and alloying elements.

4 ANNEALING, frequently referred to as FULL ANNEALING, consists of heating steels to slightly above Ac_3, holding for AUSTENITE to form, then slowly cooling in order to produce small grain size, softness, good ductility and other desirable properties. On cooling slowly the AUSTENITE transforms to FERRITE and PEARLITE.

5 NORMALIZING consists of heating steels to slightly above Ac_3, holding for AUSTENITE to form, then followed by cooling (in still air). On cooling, AUSTENITE transforms giving somewhat higher strength and hardness and slightly less ductility than in annealing.

6 FORGING RANGE extends to several hundred degrees above the UPPER TRANSFORMATION TEMPERAT URE.

7 BURNING RANGE is above the FORGING RANGE. Burned steel is ruined and cannot be cured except by remelting.

8 STRESS RELIEVING consists of heating to a point below the LOWER TRANSFORMATION TEMPERATURE, A_1, holding for a sufficiently long period to relieve locked-up stresses, then slowly cooling. This process is sometimes called PROCESS ANNEALING.

9 BLUE BRITTLE RANGE occurs approximately from 300° to 700°F. Peening or working of steels should not be done between these temperatures, since they are more brittle in this range than above or below it.

10 PREHEATING FOR WELDING is carried out to prevent crack formation. See TEMPIL° PREHEATING CHART for recommended temperatures for various steels and non-ferrous metals.

11 CARBURIZING consists of dissolving carbon into surface of steel by heating to above transformation range in presence of carburizing compounds.

12 NITRIDING consists of heating certain special steels to about 1000°F for long periods in the presence of ammonia gas. Nitrogen is absorbed into the surface to produce extremely hard "skins".

13 SPHEROIDIZING consists of heating to just below the lower transformation temperature, A_1, for a sufficient length of time to put the CEMENTITE constituent of PEARLITE into globular form. This produces softness and in many cases good machinability.

• MARTENSITE is the hardest of the transformation products of AUSTENITE and is formed only on cooling below a certain temperature known as the M_3 temperature (about 400° to 600°F for carbon steels). Cooling to this temperature must be sufficiently rapid to prevent AUSTENITE from transforming to softer constituents at higher temperatures.

• EUTECTOID STEEL contains approximately 0.85% carbon.

• FLAKING occurs in many alloy steels and is a defect characterized by localized micro-cracking and "flake-like" fracturing. It is usually attributed to hydrogen bursts. Cure consists of cycle cooling to at least 600°F before air-cooling.

• OPEN OR RIMMING STEEL has not been completely deoxidized and the ingot solidifies with a sound surface ("rim") and a core portion containing blowholes which are welded in subsequent hot rolling.

• KILLED STEEL has been deoxidized at least sufficiently to solidify without appreciable gas evolution.

• SEMI-KILLED STEEL has been partially deoxidized to reduce solidification shrinkage in the ingot.

• A SIMPLE RULE: Brinell Hardness divided by two, times 1000, equals approximate Tensile Strength in pounds per square inch. (200 Brinell ÷ 2 x 1000 = approx. 100,000 Tensile Strength, p.s.i.)

FIGURE 26-20 Iron iron-carbon phase diagram with related notes.

temperatures. Pure iron forms the **body-centered cubic (BCC)** crystal below a temperature of 1675°F (913°C). Iron changes to form the **face-centered cubic (FCC)** crystal above 1675°F (913°C). The body-centered cubic form of iron is called *alpha ferrite*, abbreviated α-Fe. The face-centered cubic form of iron is called austenite, abbreviated γ-Fe.

NOTE

The following section relates to the notes on the iron-carbon diagram in ***Figure 26-20***. The numbered paragraphs can be found printed in a column on the right side of the figure.

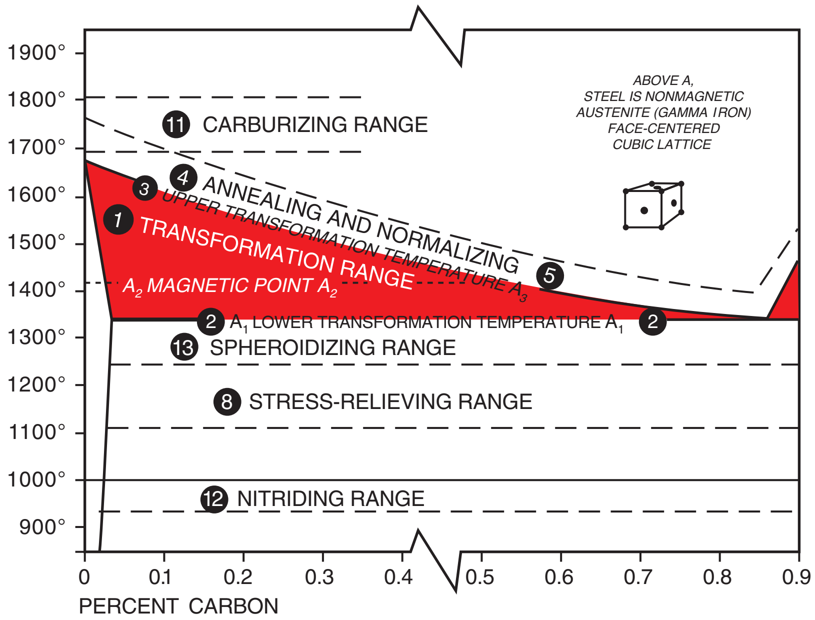


FIGURE 26-21 Transformation range.

1. **Transformation range—**In this range, steels undergo internal atomic changes that radically affect the properties of the material.

You will notice that the transformation range (1) is between lines (2) and (3). This area (1) on **Figure 26-21** is triangular, with the small end to the right. This is in the direction that the percentage of carbon in the iron increases.

2. **Lower transformation temperature (A_1)—**Termed Ac_1 on heating and Ar_1 on cooling. Below Ac_1 structure ordinarily consists of ferrite and pearlite (see 2a and 2b in this list). On heating through Ac_1 these constituents begin to dissolve in each other to form austenite (see 2d), which is nonmagnetic. This dissolving action continues on heating through the transformation range until the solid solution is complete at the upper transformation temperature.

We do not think of solids as being able to dissolve into each other, but above the lower transformation temperature (A_1) the carbon-rich cementite (see 2c) and the carbon-lean ferrite, both solids, dissolve into each other. The dissolving of one material into another as the mixture is heated is similar to dissolving salt into water, Experiment 26-3.

Ferrite, cementite, and austenite are all crystalline forms of iron and iron-carbon alloys. Their formation is based on three factors: the carbon content, temperature, and time.

- *Carbon content:* Before any of the crystal forms can be created, the correct carbon percentage must exist in the alloy.
- *Temperature:* With the correct carbon content, an iron-carbon alloy will form a specific crystal at the approximate temperature for that specific alloy, given enough time.
- *Time:* Crystal formation requires time. The more time at the correct temperature, the larger the crystals can grow. Heating is a relatively slow process compared to quenching, which can occur in a fraction of a second. Therefore, crystals tend to grow larger or change forms during heating and stay frozen in the larger size or form when cooled.

2a. Ferrite is practically pure iron (in plain carbon steels) existing below the lower transformation temperature. It is magnetic and has very slight solid solubility, less than 0.02%, of carbon. Very low carbon content alloys produce more ferrite crystals than they do other crystal forms. For this reason, these alloys are considered to be soft. Without enough carbon, these low-carbon alloys will not become very hard and brittle even if they are quenched. The inability to become hard even alongside a weld makes them easily machinable after welding.

2b. Pearlite is a mechanical mixture of ferrite and cementite in much the same way that one might mix two different colors of sand, **Figure 26-22**. Each grain of sand still retains its unique color even though it has been mixed with the other colored grains. Unlike sand, each grain of ferrite and cementite fits together like puzzle parts because as they were formed, they were all growing together.

2c. Cementite, or iron carbide, is a compound of iron and carbon, Fe_2C.

2d. Austenite is the nonmagnetic form of iron and has the power to dissolve carbon and alloying elements.

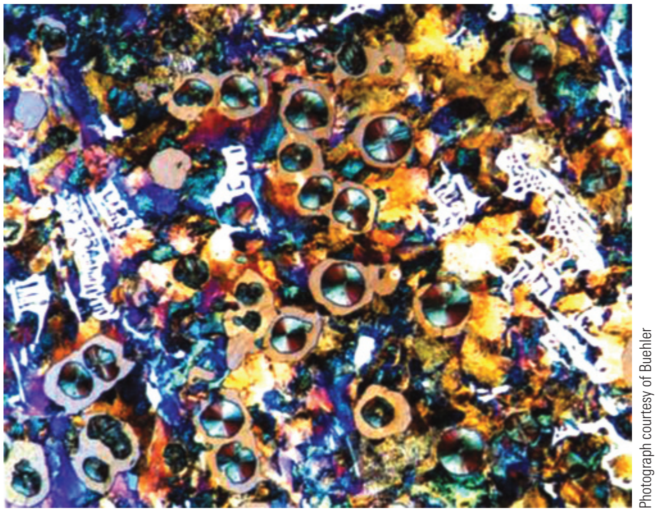


FIGURE 26-22 Microstructure of pearlitic ductile iron containing cementite (white).

An iron-carbon alloy at a low temperature can dissolve or absorb very little additional alloys. Like water and salt in Experiment 25-3, however, the higher the temperature and the longer the time, the more salt that is dissolved. In the same manner, iron will accept more alloys at higher temperatures. These new alloys may stay trapped within the iron-carbon crystal when they are cooled or they may separate. Once dissolved at high temperatures, it is usually the cooling rate or time that affects the final makeup of the iron-carbon crystals.

3. **Upper transformation temperature (A_3)**—Termed Ac_3 on heating and Ar_3 on cooling. Above this temperature the structure consists wholly of austenite, which coarsens with increasing time and temperature. The upper transformation temperature is lowered as carbon increases to 0.85% (eutectoid point).

The upper transformation temperature (A_3) line slopes downward to the right. That is because alloying carbon to iron lowers the temperature for the allotropic crystal transformation from BCC to FCC. This temperature reduction is similar to what is observed as the mixture of lead-tin approached the 80.5% lead and 19.5% tin ratios, Figure 26-18. Figure 26-19, which represents carbon content ranging from 0.0% up to 1.50%, shows more than a 200°F (100°C) drop in the melting temperature of iron-carbon alloys. The transition range starts at approximately 1675°F (912°C) and lowers to approximately 1335°F (724°C) when 0.85% carbon is present.

The temperature at which the allotropic crystal transition of ferrite to austenite occurs is so important in all heat treatments of steel that metallurgists call it the *critical temperature*.

STRENGTHENING MECHANISMS

Perhaps the most important physical characteristic of a metal is strength. Most pure metals are relatively weak. Structures built of pure metals would be more massive and heavier than those built with metals strengthened by alloying and heat-treating. Welders must understand numerous methods used to strengthen metals because improper welding techniques can significantly weaken a metal, resulting in a weld that will fail. Some of the strengthening methods used and how welding affects them are described next.

Solid-Solution Hardening

It is possible to replace some of the atoms in the crystal lattice with atoms of another metal in a process called *solid-solution hardening*. In such cases, the lattices of the solid solution and the pure metal are the same except that the lattice of the solid solution is strained as more foreign atoms dissolve. These alloyed prestressed crystals are stronger and less ductile. The amount of change in these properties depends on the number of second atoms introduced, **Figure 26-23**.

Although an important metallurgical tool, solid-solution hardening has its drawbacks. Not all metals have lattice dimensions that allow significant substitution of other atoms. The amount that can be introduced this way is therefore limited. Solid-solution hardening does have the advantage of not changing lattice structure as the result of thermal treatments. Thus, solid-solution–strengthened alloys are generally considered

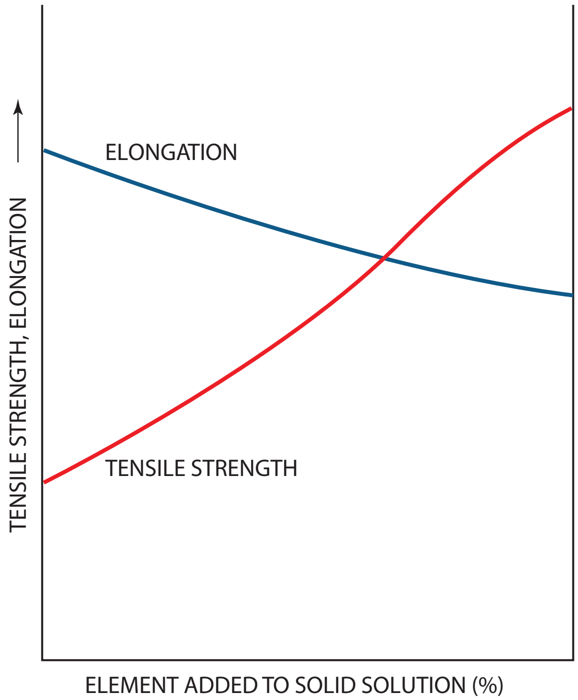


FIGURE 26-23 The general change in properties caused by the addition of other atoms in alloys, producing solid solutions.

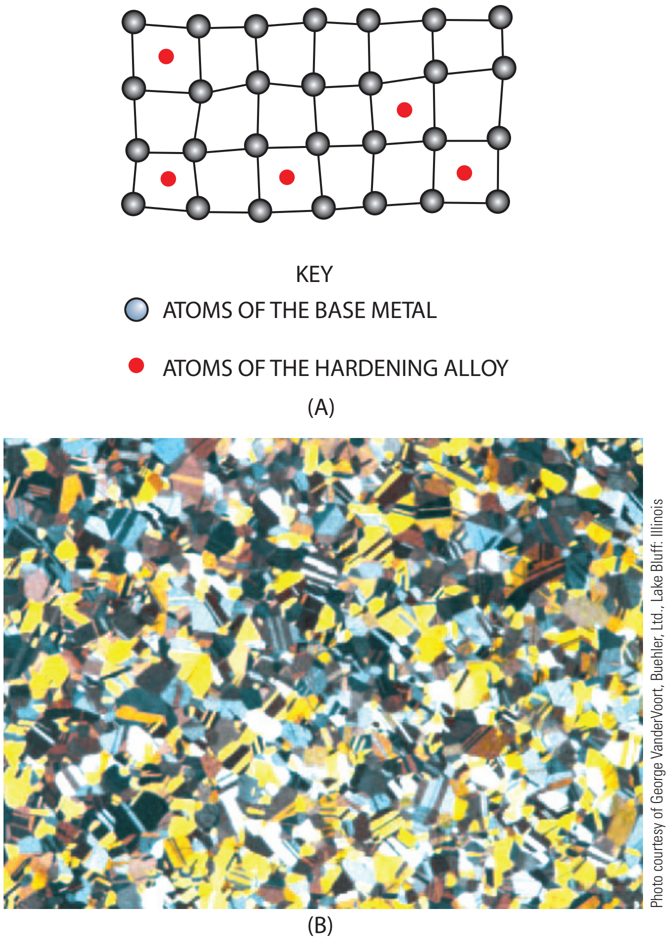


FIGURE 26-24 Solid solution.

very weldable, **Figure 26-24**. Many aluminum alloys are strengthened in this way.

Precipitation Hardening

Alloy systems that show a partial solubility in the solid phase generally have very low solubility at room temperature. Solubility increases with temperature until the alloy system reaches its solubility limit. For example, the aluminum-copper system has a solid-solution solubility of 0.25% copper at room temperature, which increases to a maximum of 5.6% copper at 1019°F (548°C). For this reason, very few, if any, aluminum alloys have more than 4.5% copper as an alloying element. These alloys reach their saturation just like a sponge saturated with water; when more water is added, it just runs off. When more alloy is added to metals, it will not be combined with the base metal.

Precipitation hardening is a heat treatment involving three steps: (1) heating the alloy enough to dissolve the second phase and form a single solid solution; (2) quenching the alloy rapidly from the solution temperature to keep the second phase in solution, thus producing a supersaturated solution; and (3) reheating the alloy with careful control of time and temperature to precipitate the second phase as very fine crystals that strengthen the lattice in which they had dissolved. This process, called *precipitation hardening* or *age hardening*, is the heat treatment used to strengthen many aluminum alloys.

EXPERIMENT 26-3

Crystal Formation

In this experiment you will be working in a small group to observe the formation of salt crystals. Using a beaker, water, salt, a spoon, a hot plate, gloves, safety glasses, and any other required safety protection, you are going to observe the ability of salt to be dissolved into water as the water is heated.

The dissolving of salt in water shows an increase in solubility as the temperature increases. Add a spoonful of salt to the beaker of cold water and stir vigorously until the salt is dissolved. This is an example of a liquid solution. If more salt is slowly added and stirring is continued, then at some point the salt will no longer dissolve into the solution. The water has now reached its solubility limit. No more salt will dissolve no matter how long the mixture is stirred.

If the beaker is heated, then the salt crystals that did not dissolve at room temperature soon disappear. Now even more salt could be added, and it would dissolve. The increasing of the solubility limits by heating has resulted in a supersaturated solution. A supersaturated solution is one that, because of heating, a higher percentage of another material can be dissolved in.

When the beaker of water is cooled to room temperature, with time the reverse action occurs. The supersaturated solution can no longer hold the salt in the solution and rejects it from the solution. In time, salt crystals reappear in the beaker.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

Mechanical Mixtures of Phases

Two phases or constituents may exist in equilibrium, depending on the alloy's temperature and composition. The mixture may consist of two different crystals, which are solid solutions of the two metals of the alloy (see the α and β area in Figure 26-18), or the mixture may consist of a single solid solution and an intermetallic compound, such as the pearlite in **Figure 26-25**. The properties of alloys that are mechanical mixtures of two phases are generally related linearly to the relative amounts of the metal's two constituents, **Figure 26-26**.

At room temperature, the iron-carbon alloy has two forms: alpha iron ferrite and cementite. The ferrite is very ductile but weak; the cementite is very strong but brittle. In a careful combination, the cementite stiffens the soft ferrite crystals, increasing their strength without losing too much ductility.

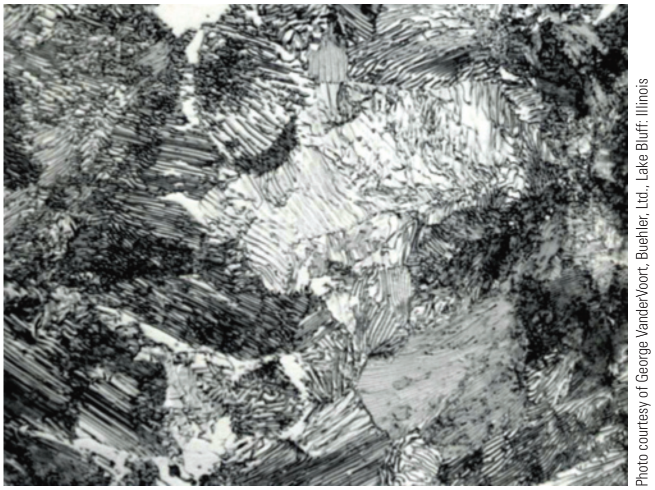


FIGURE 26-25 Pearlite.

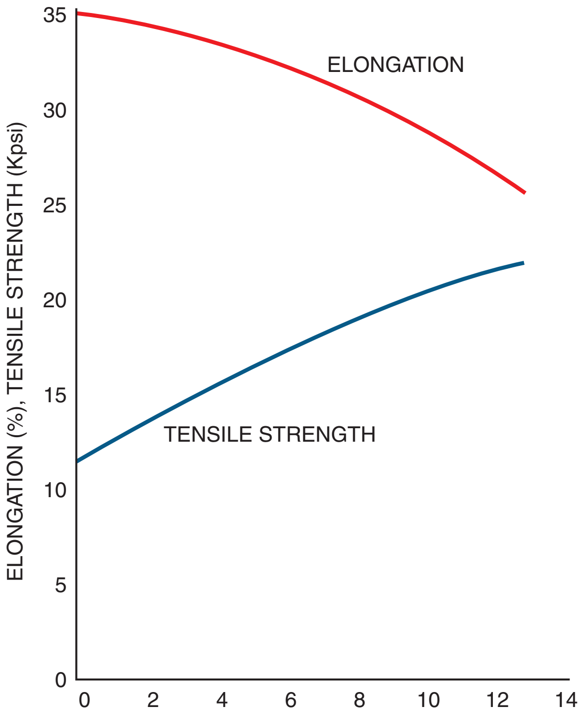


FIGURE 26-26 Change in mechanical properties caused by beta (silicon phase) in mechanical mixture with alpha (aluminum phase).

QUENCH, TEMPER, AND ANNEAL

Quenching

Quenching is the process of rapidly cooling a metal by one of several methods. The quicker the metal cools, the greater the quenching effect. The most common methods of quenching are listed from the slowest to the fastest:

- Molten salt quenching—Very slow cooling.
- Air quenching—Air is blown across the part, cooling it only slightly faster than it would cool in still air.

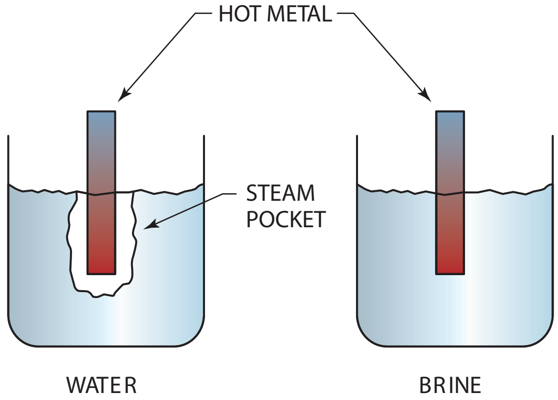


FIGURE 26-27 Effect of brine on quenching rate.

- Oil quenching—The part is immersed in a bath of oil; because oil is a poor conductor of heat, the part cools more slowly than it would in water.
- Water quenching—The part is immersed in a bath of water and cools rapidly.
- Brine quenching—The part is immersed in a saltwater solution. The salt does not allow a steam pocket to form around the part, as happens with straight water. This results in the fastest quenching time, **Figure 26-27**.

NOTE

Agitating the metal (moving it around rapidly) when it is immersed in a cooling liquid will speed up the cooling rate.

Tempering is the process of reheating a part that has been hardened through heating and quenched. The reheating reduces some of the brittle hardness caused by the quenching, replacing it with toughness and increased tensile strength.

EXPERIMENT 26-4

Effect of Quenching and Tempering on Metal Properties

In this experiment you will be working in a small group to identify the effect of quenching and tempering on metal properties. Using three or more pieces of mild steel approximately 1/4 in. (6 mm) thick, 1 in. (25 mm) wide, and 6 in. (13 mm) long, a vise with a hammer or tensile tester, a hacksaw, a file, water for quenching, two or more firebricks, a safely assembled and properly lit oxyfuel torch, pliers, safety glasses, gloves, and any other required safety equipment, you are going to observe the effect that quenching and tempering has on metal.

Heat the pieces of metal one at a time to a bright red color. Place one of them, while still red hot, between hot firebricks.

Immerse the other two into the water while they are still glowing bright red. Moving the metal in the water will ensure a faster quench.

CAUTION

The steam given off from the quenching of the hot metal can cause severe burns. Use your gloves and be careful not to allow the steam to burn you.

Set one of the pieces aside. File a smooth, clean area on the other part. Slowly heat this piece on the opposite side from the filed area using the oxyfuel torch, **Figure 26-28**. Watch the clear spot, and it will begin to change colors. It will first become a very pale yellow and gradually change to a dark blue. When the surface is dark blue, stop heating it and allow it to cool as slowly as possible between hot firebricks. The surface colors formed are called temper colors, and they indicate the temperature of the metal's surface, **Table 26-4**. The color comes from the layer of oxide formed on the hot metal's surface. The bluing on a gun barrel is the same thing, and it is used both to make the barrel stronger and to protect it from rusting. You could also use an 800°F (425°C) colored temperature-indicating crayon such as a Tempil Temperature Indicator.

After both specimens have cooled to room temperature, they can be tested. If you have a tensile testing machine, test each specimen and record its failure strength. If you do not have a tensile tester, make a 1/4-in. (6-mm)-deep saw cut on both edges of each specimen, **Figure 26-29**. Place the specimens in a vise and break them. Note how they break.

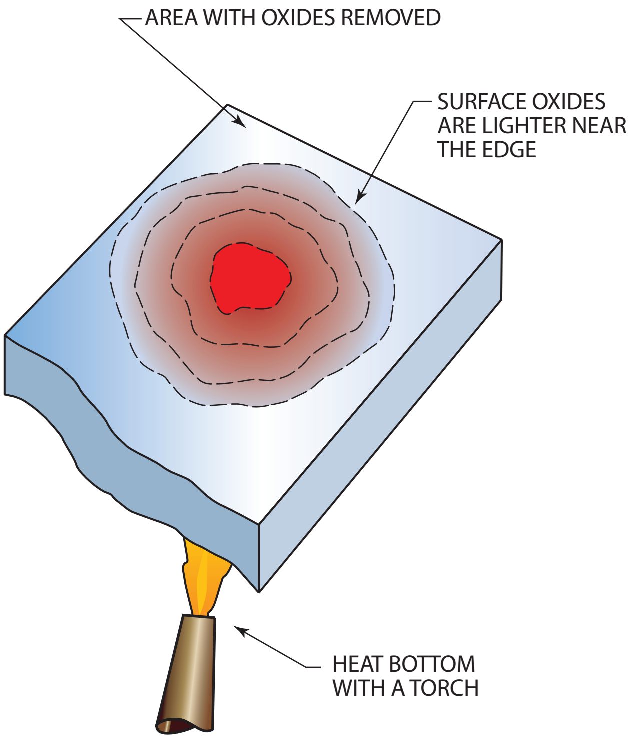


FIGURE 26-28 Surface oxide temper colors.

Degrees Fahrenheit	Color of Steel
430	Very pale yellow
440	Light yellow
450	Pale straw-yellow
460	Straw-yellow
470	Deep straw-yellow
480	Dark yellow
490	Yellow-brown
500	Brown-yellow
510	Spotted red-brown
520	Brown-purple
530	Light purple
540	Full purple
550	Dark purple
560	Full blue
570	Light blue
640	Dark blue

TABLE 26-4 Temperatures Indicated by the Colors of Mild Steel

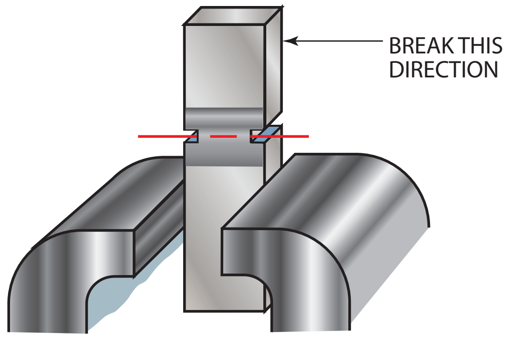


FIGURE 26-29 Knick breaking test.

Look at the fractured surface and record which has the light-colored surface and which has the darker surface. Also note which one has the smallest grain sizes shown.

This experiment can be repeated using different metals and alloys.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

Martensitic Reactions

Heating a carbon-iron alloy above the temperature at which austenite forms, see line A_3, **Figure 26-30**, and then quenching it rapidly in water is certainly not an equilibrium condition. The FCC crystals are unable to change to BCC because the rapid cooling was too fast to allow change.

Martensite is the hardest of the transformation products of austenite and is formed only on cooling below a certain temperature known as the M. temperature (approximately 400°F to 600°F [200°C to 315°C] for carbon steels).

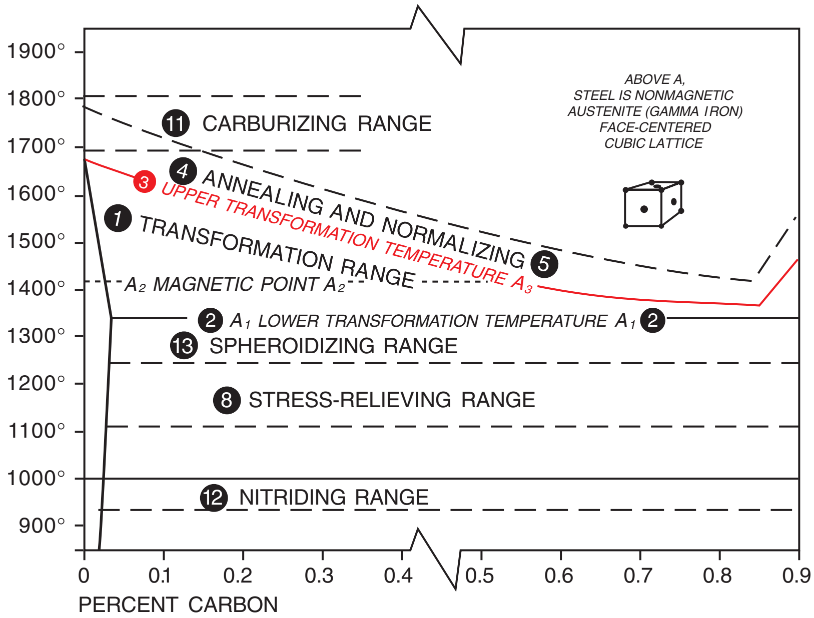


FIGURE 26-30 Upper transformation temperature.

Cooling to this temperature must be sufficiently rapid to prevent austenite from transforming to softer constituents at higher temperatures. As formed, martensite is very hard and brittle and useless for most engineering applications.

When martensite is viewed under a very high magnification, it has an **acicular (needle-like) structure**, **Figure 26-31**. During welding of medium- and high-carbon steels, the cooling rates can be fast enough to produce the undesirable martensite. Martensite formation can be minimized by preheating the steel to slow the cooling rates. If the surrounding metal is warmed by preheating, the weld does not lose its temperature as quickly, **Figure 26-32**.

Martensite can be tempered to a more useful structure at a temperature below the lower critical temperature, see line A_1 in **Figure 26-33**. The exact temperature, determined by the carbon content and other alloying elements, is generally furnished by the steelmaker.

When martensite is tempered, some of the carbon atoms that were trapped interstitially (small holes in the crystalline lattice) between the iron atoms are allowed to defuse out, **Figure 26-34**. The precipitation of the trapped carbon atoms allows the body-centered tetragonal crystal to reform into

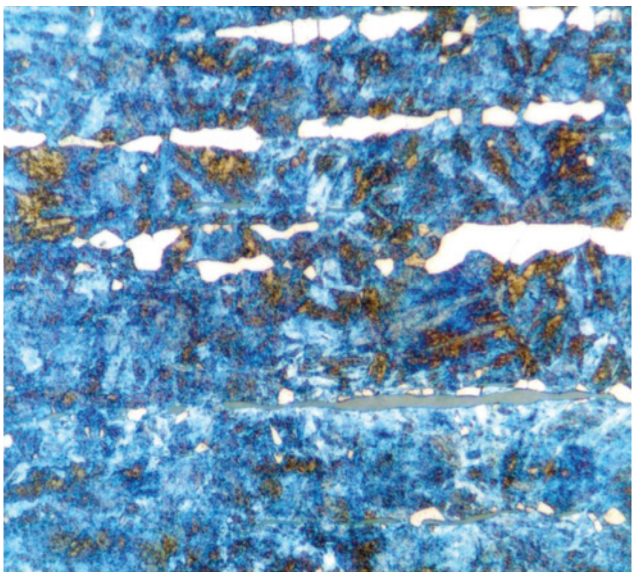


Photo courtesy of George VanderVoort, Buehler, Ltd., Lake Bluff: Illinois

FIGURE 26-31 Microstructure of type 416 martensitic stainless steel.

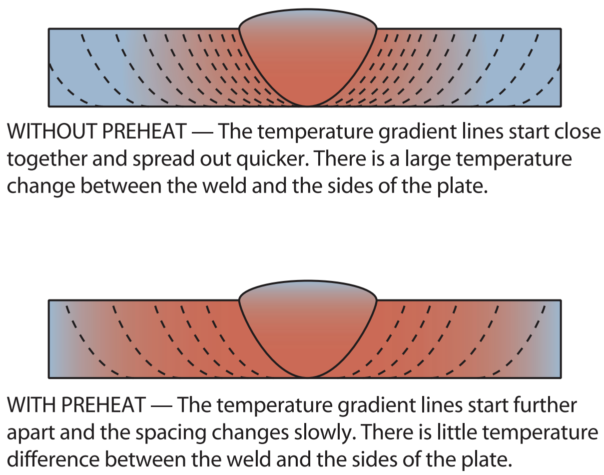


FIGURE 26-32 Temperature gradient lines with and without preheating.

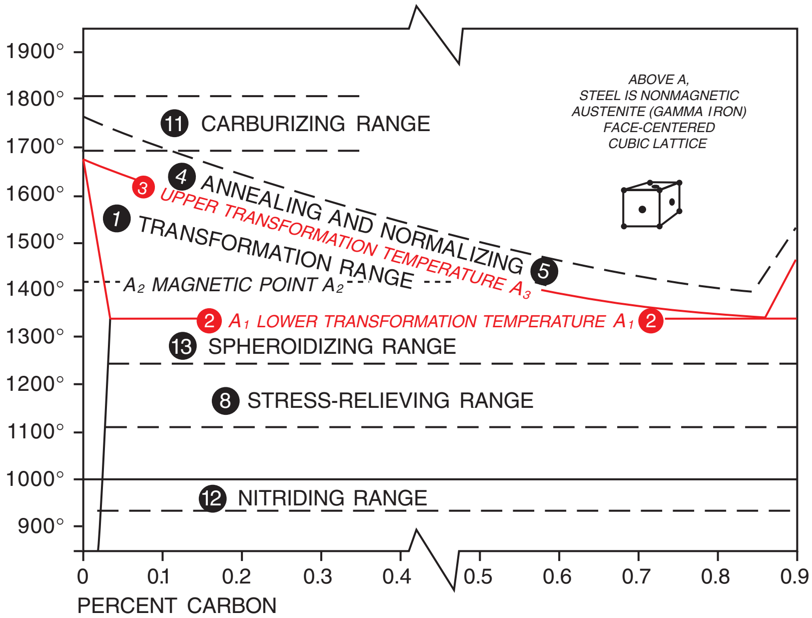


FIGURE 26-33 Transformation range.

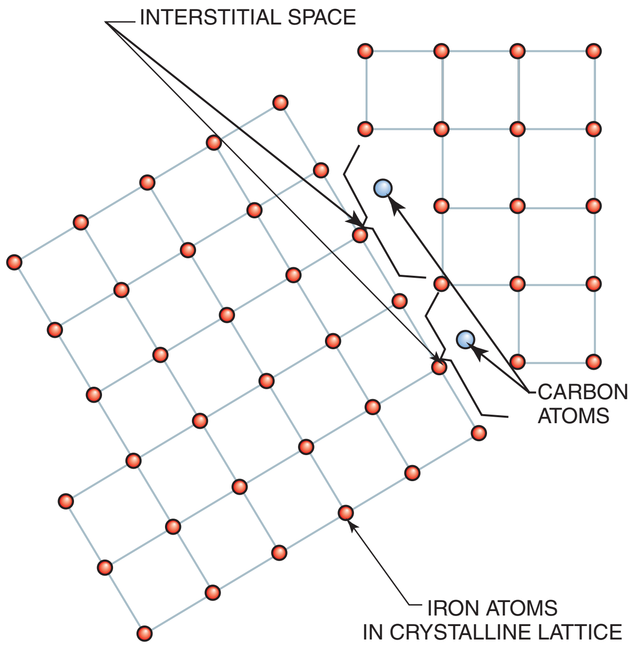


FIGURE 26-34 Interstitial spacing.

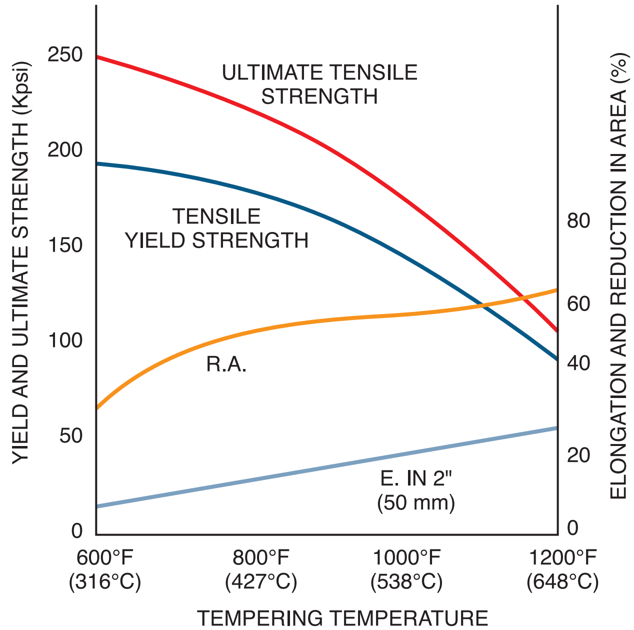


FIGURE 26-35 Changes in properties of SAE 1050 martensite caused by tempering.

the body-centered cube crystal shape, relieving the internal strain. The microstructures of tempered and untempered martensite look very much alike. In this condition, the tempered martensite is very strong and tough.

As the tempering time and/or temperature is increased, the structure changes to a **spheroidized microstructure**. In this state, the steel is in the soft or annealed condition. For example, when a chisel, drill bit, or slag hammer is overly ground so that the sharp edge has turned blue, this indicates that a temperature of approximately 600°F (316°C) has been reached. A temperature this high causes over-tempering and softens the edge. Thus, time and temperature are critical variables in the loss of strength and hardness, **Figure 26-35**.

NOTE

For all practical purposes, plain carbon steels with less than 0.30% carbon cannot be hardened through heat-treating and quenching.

Cold Work

When metals are deformed at room temperature by cold rolling, drawing, or swaging, the grains are flattened and elongated. Complex movements occur within and between the grains. These movements distort and disrupt the crystalline structure of the metal by markedly increasing its strength and decreasing its ductility. The presence of impurities or alloying elements in metals causes them to work harder more quickly. Sheets, bars, and tubes are intentionally cold-worked to increase their strength because cold working will strengthen almost all metals and their alloys.

The cold-worked structure can be annealed by heating the metal above the **recrystallization temperature**. Above that temperature new crystals grow. The size of the new grains depends on the severity of the prior cold working and the time above the recrystallization temperature. The final annealed structure is weaker and more ductile than the cold-worked structure. The final properties depend primarily on the alloy and on the grain size. The coarse-grained metals are weaker.

Grain Size Control

One of the few metallurgical effects common to all metals and their alloys is grain growth. When metals are heated, grain growth is expected. The rate of growth increases with temperature and the length of time at that temperature. There are charts that show the effect of time and temperature on the austenite grain growth. These are called time-temperature-transformation (TTT) charts. The process involves larger grains devouring smaller grains. Coarse grains are weaker and tend to be more ductile than fine grains.

The longer the metal is held at a high temperature, above A_3, the larger the grain size. (See the left vertical strip on Figure 26-20.) The austenite crystals will grow so large that when they are cooled and transformed into pearlite their large size can be seen easily in a fracture. Some welders know that this large grain is detrimental to the metal's strength and often refer to it as having been "crystallized."

The production of fine grains is not as simple because large grains cannot be shrunk. Reducing the grain size requires the creation of fresh grains by heating the metal to the austenite range and quenching it to recrystallize it. This technique is common to all metals and alloys. The same results can be obtained with an allotropic transformation.

Allotropic transformation also requires the creation of fresh grains. Because the temperatures of allotropic transformation are high, the new grains begin to grow almost immediately. To obtain a fine-grained structure, the metal must be heated quickly above the critical temperature, line A_3 in Figure 26-30, and cooled quickly in a process called **grain refinement**. Not all metals exhibit allotropic transformation. Fortunately, iron does, and this is one reason that steels are such versatile materials.

HEAT TREATMENTS ASSOCIATED WITH WELDING

Welding specifications frequently call for heat-treating joints before welding or after fabrication. To avoid mistakes in their application, welders should understand the reasons for these **heat treatments**.

Preheat

Preheat is used to reduce the rate at which welds cool. Generally, it provides two beneficial effects—lower residual stresses and reduced cracking. The lowest possible temperature should be selected because preheat increases the size of the heat-affected zone and can damage some grades of quenched and tempered steels. The amount of preheat generally is increased when welding stronger plates or in response to higher levels of hydrogen contamination.

Area 10, "Preheating Range for Welding," **Figure 26-36**, shows the temperature range for preheating various

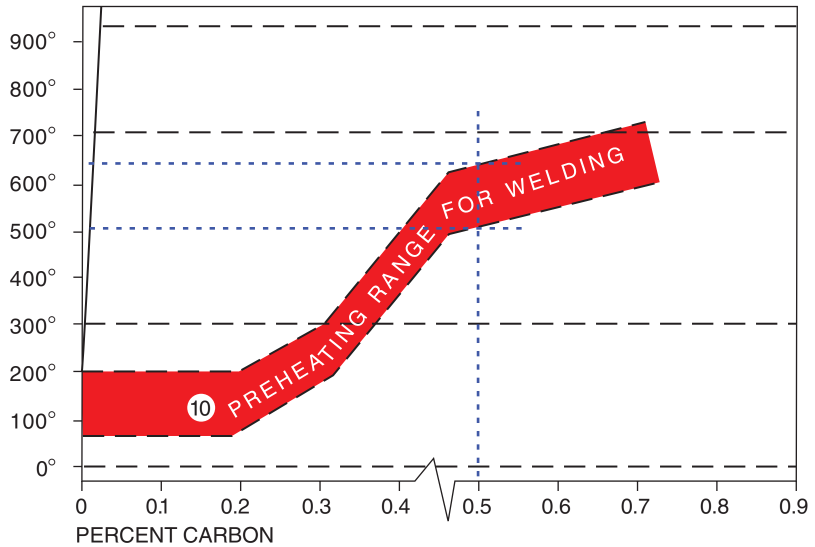


FIGURE 26-36 Preheating range for welding.

	Plate Thickness (inches)			
ASTM/ AISI	1/4 or less	1/2	1	2 or more
A36	70°F	70°F	70°F	150°F to 225°F
A572	70°	70°	150°	225° to 300°
1330	95°	200°	400°	450°
1340	300°	450°	500°	550°
2315	Room temp.	Room temp.	250°	400°
3140	550°	625°	650°	700°
4068	750°	800°	850°	900°
5120	600°	200°	400°	450°

TABLE 26-5 Recommended Minimum Preheat Temperatures for Carbon Steel

iron-carbon alloys. As the preheat area moves to the higher carbon percentage side, it rises in temperature. This is because as the percentage of carbon increases, the alloy becomes more susceptible to hardening and cracking due to rapid cooling. Preheating charts are available for recommended temperatures for various steels and nonferrous metals, **Table 26-5**.

The most commonly used preheat temperature range is between 250°F and 400°F (121°C and 204°C) for structural steel. The preheat temperatures can be as high as 600°F (316°C) when welding cast irons.

Care must be taken to soak heat into the region of the intended weld. Superficial heating is not enough because the purpose is to affect the rate at which a relatively large weld cools. To prevent problems and ensure uniform heating, the temperature of the preheated section should be measured at least 10 and 20 minutes after heating.

Stress Relief, Process Annealing

Residual stresses are unsuitable in welded structures, and their effects can be significant. The maximum stresses generally equal the yield strength of the weakest material associated with a specific weld. Such stresses can cause distortion, especially if the component is to be machined after welding. They can also reduce the fracture strength of welded structures under certain conditions.

Area 8 of **Figure 26-37**, "Stress-Relieving Range," consists of heating to a point below the lower transformation temperature, A_1, holding for a sufficiently long period to relieve locked-up stresses, then slowly cooling. This process is sometimes called process annealing.

The yield strength of steels decreases at higher temperatures. When heated, the residual stresses will drop to conform to the lower yield strength; thus, the higher the temperature, the better. But significant changes caused by overheating, overtempering, grain growth, or even a phase change must be avoided. Therefore, the temperatures selected must be less than the tempering temperature used to heat-treat the plate. Regardless of the plate's metallurgical structure, these temperatures must be kept below the critical temperature.

The most commonly used temperature range for stress relief steel is between 1100°F and 1150°F (593°C and 620°C). This range is high enough to drop the yield residual stresses by 80% and low enough to prevent any harmful metallurgical changes in most steels. While risky, heating to just under the critical temperature does offer a stress reduction of approximately 90%. Caution should be exercised, however, because some steel will become brittle after thermal stress relief.

Time at temperature is also an important factor because it takes time to bring the center of a weldment to the desired temperature. One hour at temperature is the minimum, and 6 hours offer an additional 10% drop in stress. However, the longer a part is held at temperature, the greater the fuel cost. Therefore, it is necessary to determine if the additional 5 hours at temperature is worth the 10% drop in stress.

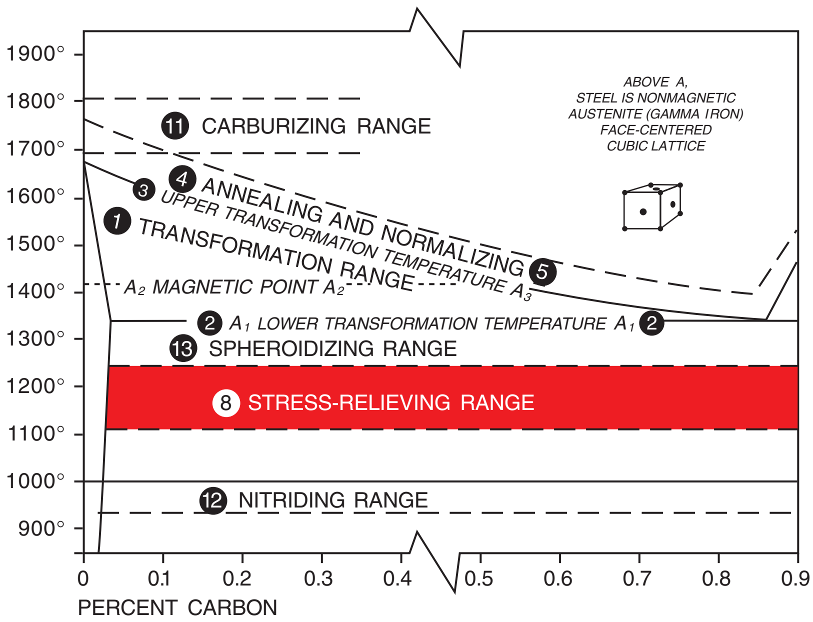


FIGURE 26-37 Stress-relieving range.

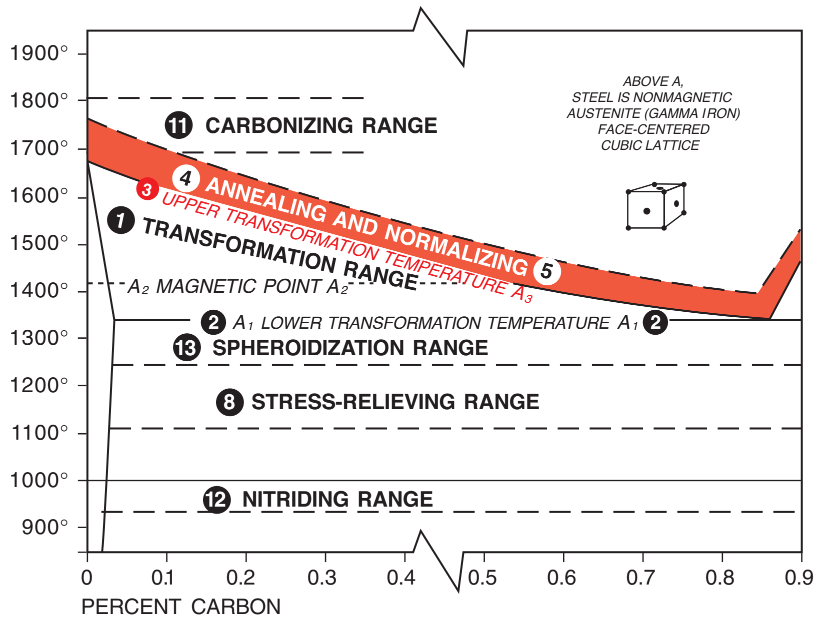


FIGURE 26-38 Annealing and normalizing.

Before cooling, the component must be uniformly heated. That requirement alone generally ensures the component will be at temperature long enough to relieve the stresses. The rate of cooling must also be considered. Rapid cooling results in uneven cooling (as in welding) and causes a new set of residual stresses. Ideally, the cooling rate is slow enough to cool the entire mass of the metal uniformly.

Annealing

Annealing, frequently referred to as full annealing, involves heating the structure of a metal to a high enough temperature, slightly above Ac_3, to turn it completely austenitic. See **Figure 26-38**, area 4. After soaking to equalize the temperature throughout the part, it is cooled in the furnace at the slowest possible rate. On cooling slowly, the austenite transforms to ferrite and pearlite. The metal is now its softest, with small grain size, good ductility, excellent machinability, and other desirable properties.

Normalizing

Area 5 of Figure 26-38, "Annealing and Normalizing," consists of heating steels to slightly above Ac_3, holding for austenite to form, and then cooling (in still air). On cooling, austenite transforms, giving somewhat higher strength and hardness and slightly less ductility than in annealing.

TIME-TEMPERATURE-TRANSFORMATION (TTT) DIAGRAMS

Grain growth is a function of time and temperature. So, when welding, the length of time a metal is at an elevated temperature and the rate at which it is cooled have a significant effect on the weld and surrounding metal's properties. Understanding these phenomena is important to welders because as a weld is being made, the surrounding metal is being affected. Therefore, the speed of a weld and the temperature of the surrounding metal will affect the transformation of the grain structure in the surrounding area called the heat-affected zone (HAZ).

Martensite

The high temperatures along the sides of a weld in steel transform into austenite grain structure. Austenite can then be transformed into three different grain structures depending on the rate of cooling, **Figure 26-39**. If the austenite is cooled too quickly, it will transform into

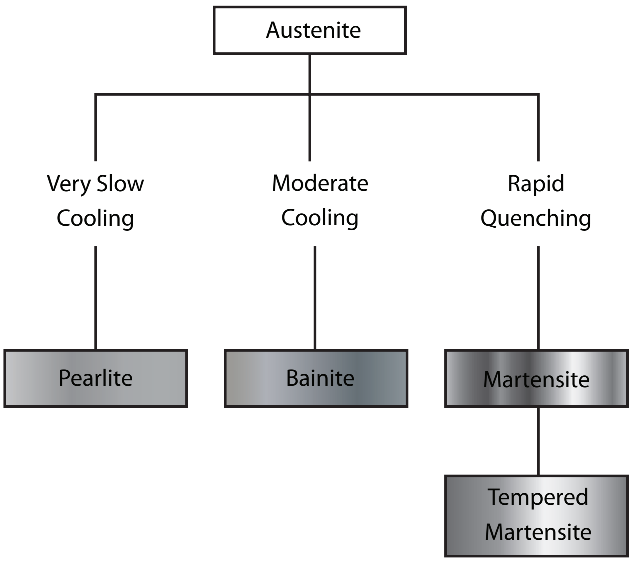


FIGURE 26-39 Austenite transformations.

martensite, which is a very large, hard, and brittle grain structure with almost no ductility. If it remains, it is highly susceptible to heat-affected zone cracking.

Bainite

At temperatures between 480° and 900°F (250° and 500°C), bainite grain structure is formed. It is hard and strong but has some ductility.

Pearlite

At temperatures below the bainite range for an alloy, pearlite grain structures are formed. Pearlite is a layered combination of cementite (Fe_3C) and ferrite (Fe). The carbon in cementite makes it harder than the almost pure ferrite. Together these structures combine to make a more ductal form of steel.

TTT Diagrams

As previously stated, grain transformation is a function of both time and temperature. Because the transformation of some metals may take place in fractions of a second while others may take hours or days, the time scale at the bottom of the TTT diagram is compressed. So each equal movement along the timeline to the right represents a longer period of time starting with 1 second, then 1 minute, and so on.

Figure 26-40 and **Figure 26-41** show examples of the transformation of austenite grain structure into pearlite grain structure. The transformation occurs on the horizontal line between lines M_S and M_F. As shown in Figure 26-40, when the transformation occurs slowly at a higher temperature over a longer period of time, it results in a coarse pearlite grain structure. During the transformation, as illustrated by point (B), the ferrite and cementite grain structures develop within the boundaries of each austenitic grain structure. Point (B) is a representation of the completed transformation.

Figure 26-41 illustrates the transformation that would occur at a lower temperature than was shown in Figure 26-40. Although the cementite and ferrite grain structures develop similarly within the austenite grain boundaries, the more rapid cooling that would occur at this lower temperature results in a much finer pearlite structure. Point (F) is a representation of the completed transformation.

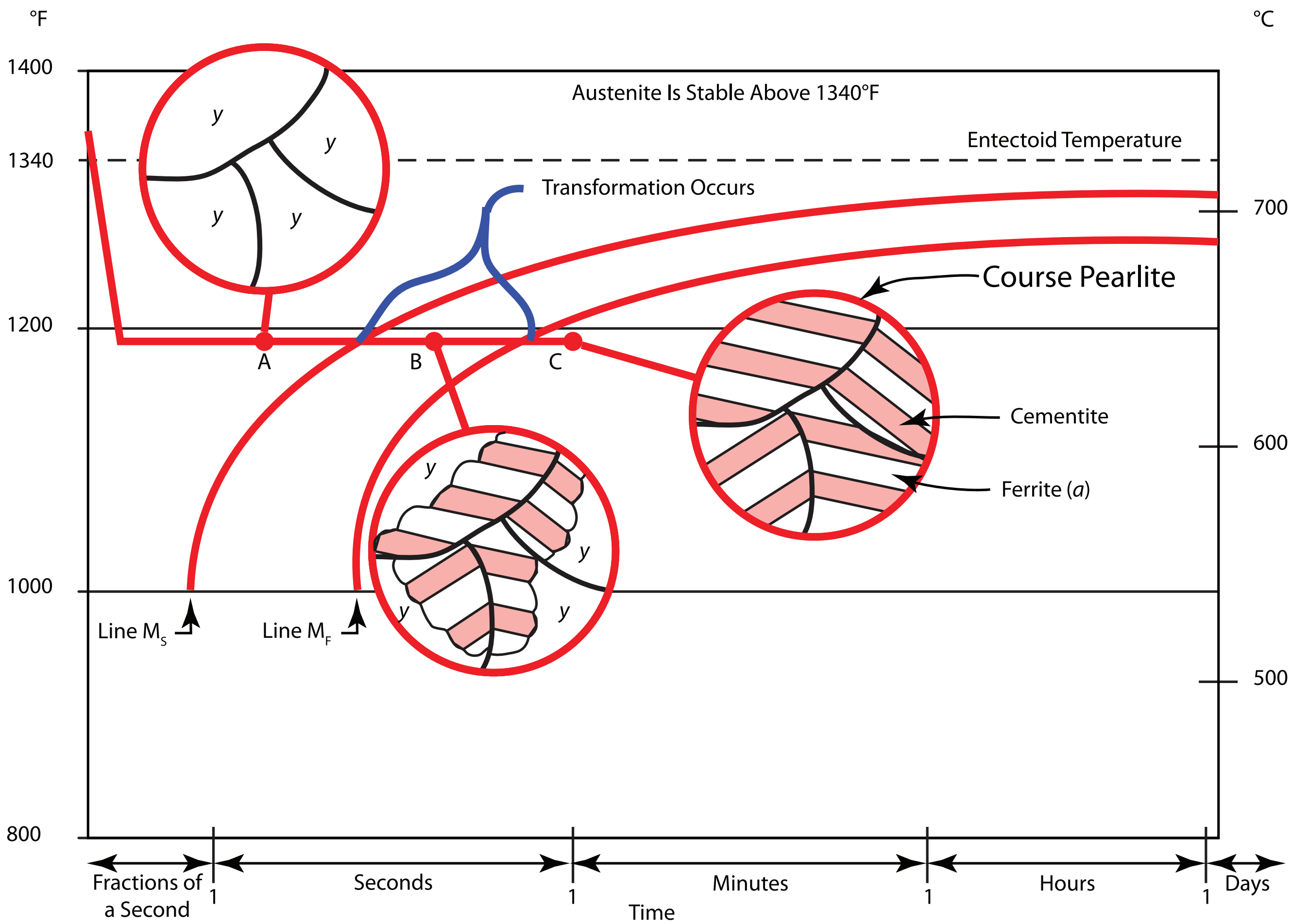


FIGURE 26-40 Time-temperature-transformation diagram for coarse pearlite.

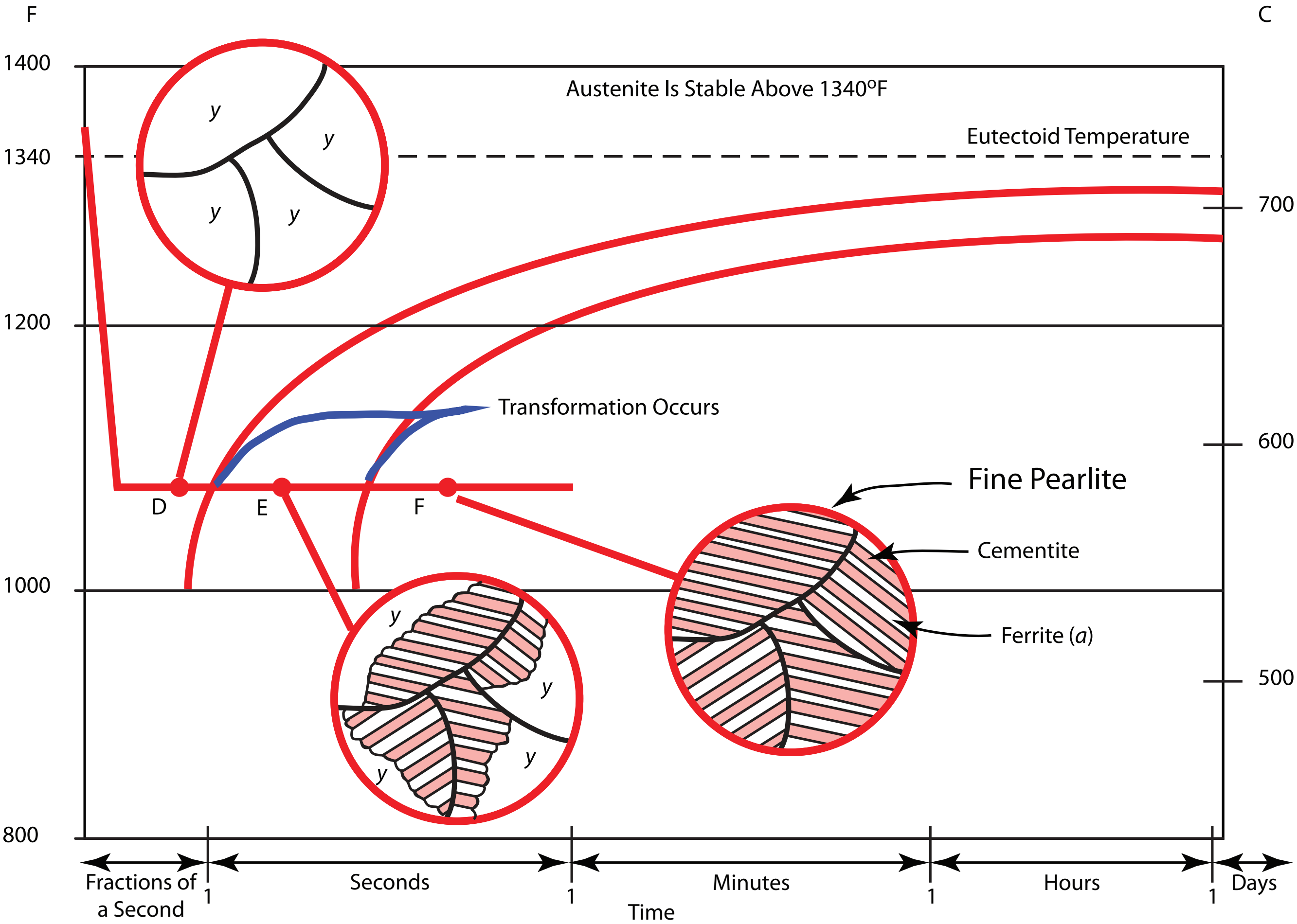


FIGURE 26-41 Time-temperature-transformation diagram for fine pearlite.

> **NOTE**
>
> As observed in Experiment 26-3, when given enough time, crystals tend to grow larger, just like the increased time allowed the coarse pearlite grain structures to develop.

The difference between a fine or course grain structure can be illustrated by comparing the difference between wet gravel and wet sand. Wet gravel can be carefully stacked in a relatively vertical pile; however, if bumped, the stack will easily slide apart. Wet sand can be piled up vertically and if bumped, only a small part may be dislodged. In the same way, fine pearlite is softer and more ductal than is coarse pearlite.

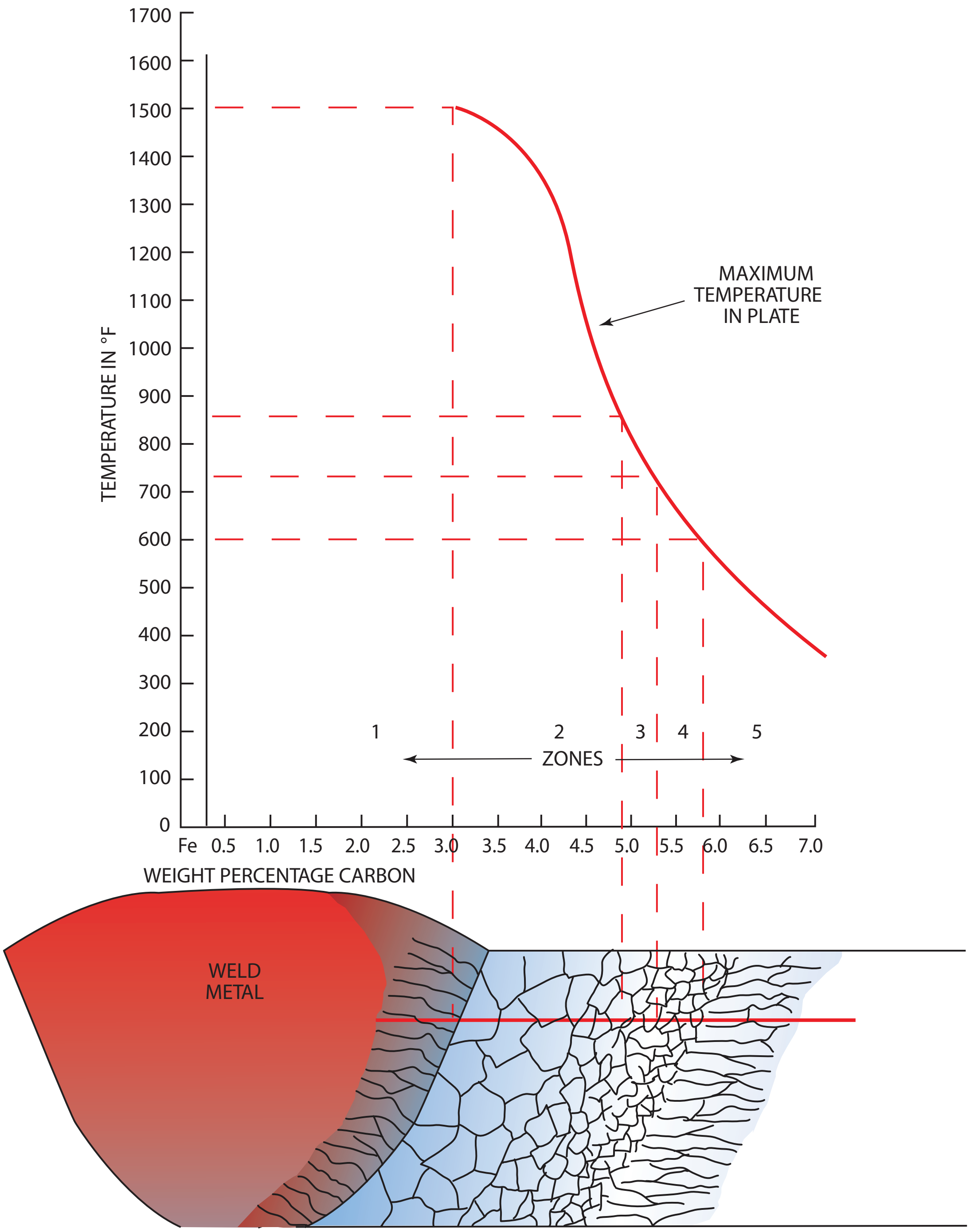
THERMAL EFFECTS CAUSED BY ARC WELDING

During arc welding, liquid weld metal is deposited on the base metal, which is at or near room temperature. In the process, some of the base metal melts from contact with the liquid weld metal and arc, flame, and so on. Conduction, convection, and radiation pull the heat out of the weld metal. This causes the temperature of the deposited weld metal to cool until it becomes solid. Within a few seconds, the weld and base metal have gone from being a solid at room temperature to a liquid and back to a solid near room temperature. The time-temperature-transformation that occurs during welding is significant and can have a profound effect on the weld's fitness for service.

Heat-Affected Zone (HAZ)

The grain structure and metallurgical changes that occur in the heated region are inevitable. The lowest temperature along the sides of the weld that has any changes sets the outer extremity of the zone of change. That region of change is called the **heat-affected zone**, abbreviated **HAZ**, **Figure 26-42**. The exact size and shape of the HAZ are affected by a number of factors:

- *Type of metal or alloy:* Some metals are easily affected even by small temperature changes, whereas others are more resistant. In work-hardened metals, the heat-affected zone is defined by the recrystallization temperature, **Figure 26-43**. In age-hardened alloys,



Zone 1 – Liquid metal and the beginning of grain growth
Zone 2 – Austenitic; grain growth at high temperature, fine grain at low temperature
Zone 3 – Austenite + ferrite; grain refined and grain growth
Zone 4 – Recrystallization
Zone 5 – Cold-worked steel 0.2% carbon

FIGURE 26-42 Changes in grain structure caused by heating steel plate into different zones of the iron iron-carbon phase diagram.

this temperature is the lowest temperature at which evidence of overaging is seen, **Figure 26-44**. In quenched and tempered steels, it is the temperature at which over-tempering is seen.

- *Method of applying the welding heat:* Some heat sources, such as plasma arc welding (PAW), are very concentrated. This high-intensity welding process can have an HAZ area that is only a few thousandths of an

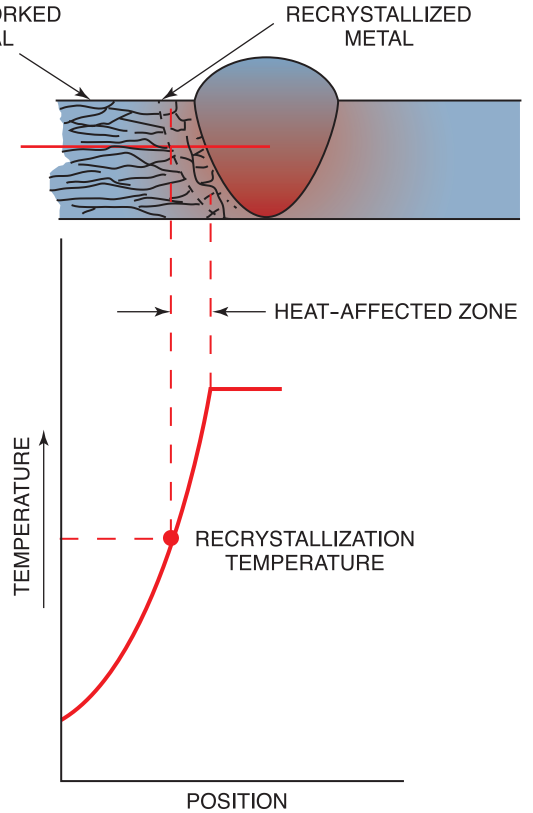


FIGURE 26-43 A heat-affected zone in cold-worked metal. The zone is defined by a change from the cold-worked grains to the recrystallized grains.

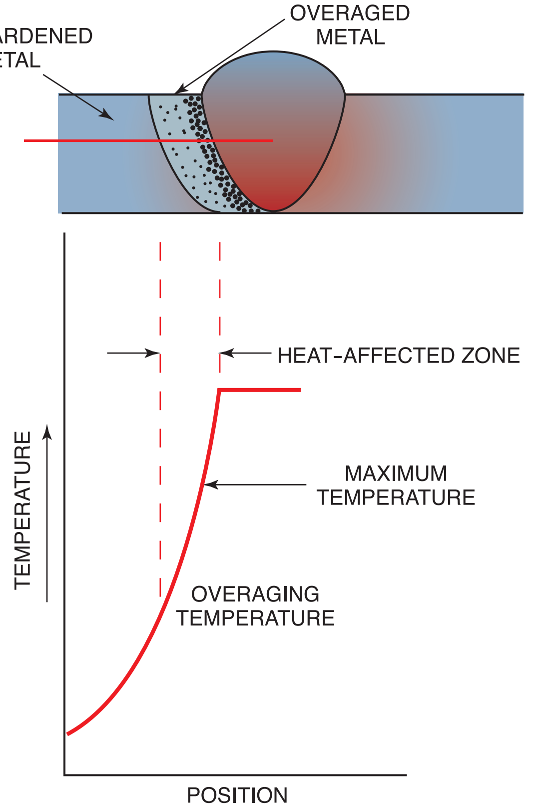


FIGURE 26-44 Heat-affected zone in age-hardened metal.

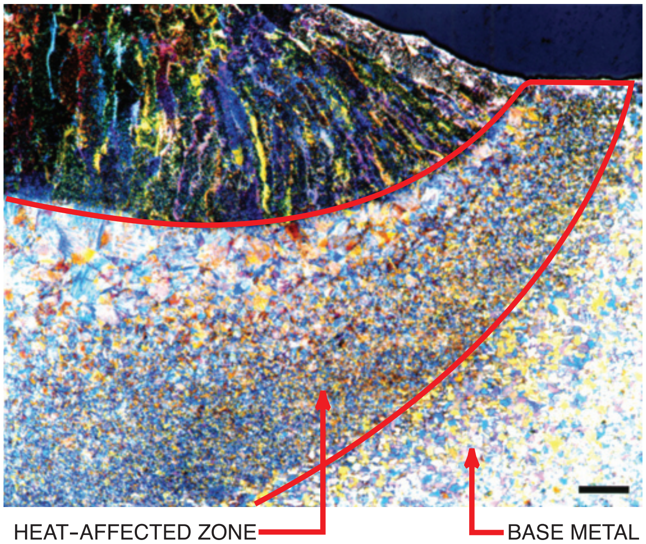


Photo courtesy of George VanderVoort, Buehler, Ltd., Lake Bluff: Illinois

FIGURE 26-45 Heat-affected zone.

inch wide. Oxyacetylene welding (OFW) is a much less intense heating source, and the resulting HAZ will be very large.

- *Mass of the part:* The larger the piece of metal being welded, the greater its ability to absorb heat without a significant change in temperature. Very large weldments may not have a noticeable temperature increase, whereas small parts may almost completely reach the melting temperature. The more metal that gets hot, the larger the HAZ.
- *Preheating and postheating:* As the temperature of the base metal increases—whether from preheating or postheating or the welding process itself—the larger the HAZ. A cold plate may have an extremely narrow HAZ.

The HAZ need not always be small. A larger HAZ is desirable for welding steels that can produce martensite at the same cooling rates as those produced when welding heavy plate. The welder can slow the cooling rates to tolerable levels by preheating the plate and thus increasing the size of the HAZ. In this case, a large HAZ is safer than contending with a brittle martensitic structure.

An important feature of the HAZ, caused by high temperatures, is the severe grain growth at the fusion line. With steels at this critical temperature, the HAZ also produces fine grains as a result of the **allotropic transformation**. **Figure 26-45** is an example of a weld that shows the HAZ in cross-section. Regardless of the alloy, the welder must control the HAZ, whether that control is to make it large or small.

GASES IN WELDING

Many welding problems and defects result from undesirable gases that can dissolve in the weld metal, **Figure 26-46**. Except for the inert gases argon and helium, discussed in Section 4, "Gas Shielded Welding," the other common gases either react with or dissolve in the molten weld pool.

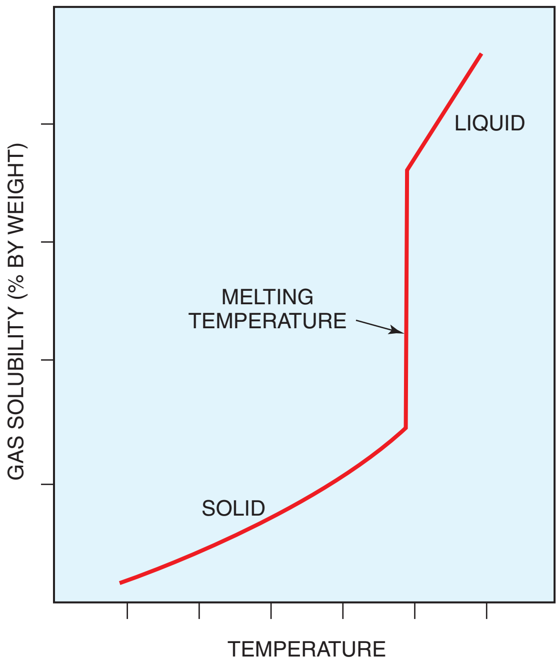


FIGURE 26-46 Typical change of solubility of "active" gases in metals.

Those that dissolve have a very high solubility in liquid metal but a very low solubility in solidified weld metal. Thus, during the freezing process, the dissolved gases try to escape. With very slow solidification rates, the gases escape. With very high solidification rates, they become trapped in the metal as supersaturated solutes. At intermediate rates of solidification, they become trapped as gas bubbles, causing porosity. Some, such as hydrogen, produce other problems as well.

Nitrogen

Nitrogen comes from air drawn into the arc stream. In GMAW processes, it results from poor shielding or strong drafts that disrupt the shield. In SMAW processes, nitrogen can result from carrying an excessively long arc. The primary problem with nitrogen is porosity. In high-strength steels, it can cause a degree of embrittlement that results in marginal toughness.

Some alloys, such as austenitic stainless steels and metals such as copper, have a high solubility for nitrogen in the solid state. This high solubility does not cause porosity in those materials. Because nitrogen improves the strength of stainless steels, it sometimes is added intentionally to shield gases used when making GTA or GMA welds in them. In Europe, it is used for welding copper to increase the arc energy with GTA welding.

Oxygen

As with nitrogen, the common source of oxygen contamination, air, reaches the weld because of poor shielding or excessively long arcs. However, metallurgical changes, not porosity, cause most of the effects of oxygen. Oxygen causes the loss of oxidizable alloys such as manganese and silicon, which reduces strength, produces inclusions in weld metals, which reduce their toughness and ductility, and causes an oxide formation on aluminum welds, which affects appearance and complicates multipass welding.

Approximately 2% of oxygen is added intentionally to stabilize the GMAW process when welding steels with argon shielding. At this concentration, oxygen does not cause the metallurgical problems listed previously. Nevertheless, the amount used must be very carefully controlled because the amount needed varies, depending on the alloys being welded. Mixtures containing only enough oxygen to do an effective stabilizing job should be used. Any more could cause problems, particularly with sensitive alloys.

Carbon Dioxide

Carbon dioxide is an oxygen substitute for stabilizing GMAW processes using argon shields, although approximately 5% to 8% carbon dioxide is usually added to produce the same effects achieved with 2% oxygen. However, the carbon in carbon dioxide is a potential contaminant that can cause problems with corrosion resistance in the low-carbon grades of stainless steels. Even straight carbon dioxide shielding has this problem. In most cases, carbon dioxide levels less than 5% do not seem to increase the carbon content of stainless steels enough to cause difficulty.

Hydrogen

Hydrogen has many sources, including moisture in electrode fluxes, very humid air, damp weld joints, organic lubricants, rust on wire or on joint surfaces or in weld joints, organic items such as paint, cloth fibers, dirt in weld joints, and others.

Hydrogen problems are avoidable by keeping organic materials away from weld joints, keeping the welding consumables dry, and preheating the components to be welded. Preheating slows the cooling rate of weldments, allowing more time for hydrogen to escape. Generally, the recommended preheat temperatures range between 250°F and 350°F (121°C to 176°C). In the case of very high-strength materials, the acceptable preheat temperatures will exceed 400°F (204°C). Low-temperature preheating of materials before welding can also remove any moisture condensed on the weld joint.

Hydrogen is the principal cause of porosity in aluminum welds and with GMAW welds on stainless steels. It can also cause random porosity in most metals and their alloys.

Even in amounts as low as five parts per million, hydrogen can cause cold cracking in high-strength steels. Hydrogen-induced cracking requires three conditions: (1) a high-stress state; (2) a martensitic microstructure; and (3) a critical level of hydrogen. The first two conditions are typical of quenched and tempered steels. With them, the critical amount of hydrogen is inversely proportional to the stress state; in other words, the stronger steels can tolerate less hydrogen. The welder must use dry electrodes and dry submerged arc fluxes to avoid the hydrogen, in the form of

moisture, when welding steels with strength levels above 80,000 psi (5624 kg/cm^2).

METALLURGICAL DEFECTS

Cold Cracking

Cold cracking is the result of hydrogen dissolving in the weld metal and then diffusing into the heat-affected zone. Hydrogen can exist in two forms—atomic or molecular, **Figure 26-47**. The heat of the arc causes the stable molecular hydrogen molecule to separate into two unstable atomic hydrogen atoms. The single atoms of atomic hydrogen can be dissolved into molten weld metal. However, as the metal cools and begins forming solid metal, the hydrogen atoms are no longer soluble, so they are forced out into the grain boundaries. Over time, these single unstable hydrogen atoms begin moving between the grain boundaries so that they can combine with another hydrogen atom to form the stable molecular hydrogen. When there are only a few hydrogen molecules formed, they do not cause problems. However, in higher-strength steels if enough hydrogen molecules collect in an area, a cold crack can occur.

It may take hours or even days for cold cracks to develop. For that reason, it is also known as hydrogen-induced cracking and delayed cracking. This cracking is most commonly found in the course grains of the HAZ, just under the fusion zone. For this reason, it is also called underbead cracking. Generally, these cracks do not surface and can be seen only in radiographs or by sectioning welds. Sometimes they surface in a region of the weld running parallel to the fusion zone. With high-strength steels, hydrogen-induced cracking occurs as transverse cracks in the weld metal that are seen easily with very low magnification, **Figure 26-48**.

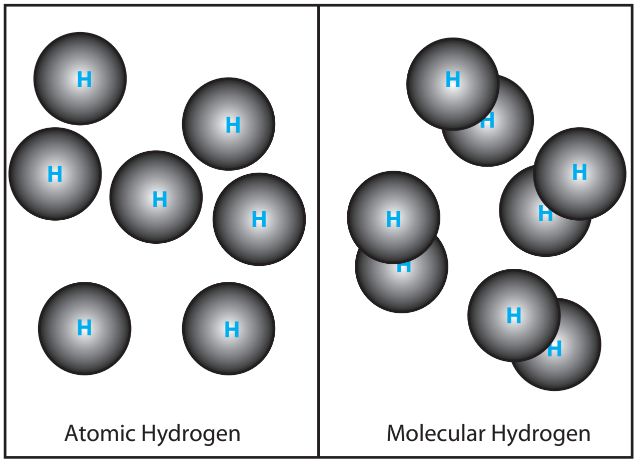


FIGURE 26-47 Atomic and molecular hydrogen.

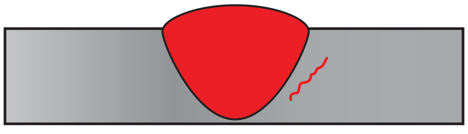


FIGURE 26-48 Underbead cracking.

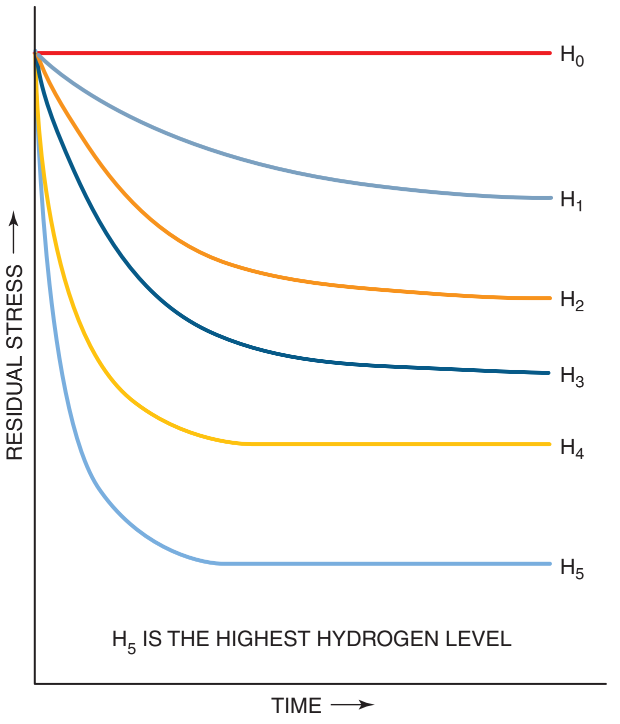


FIGURE 26-49 The time needed to develop hydrogen-induced cracking decreases at higher stresses and at higher hydrogen levels.

Hydrogen-induced cracking requires high stress, a microstructure sensitive to hydrogen, and, of course, hydrogen. The first two are almost always satisfied with high-strength quenched and tempered steels. The third depends on the welding process, the filler metals, and the preheat, as discussed previously.

Another factor is time. Under very severe conditions, cracking can occur in minutes. With very marginal conditions, cracks might not appear for weeks. For this reason, welds often are not radiographed for weeks to allow time for any potential cracks to develop.

Figure 26-49 illustrates how stress, time, and hydrogen interact to produce such cracks. These cracks never occur with 0% hydrogen, even with very high yield strength steels. To prevent cracking at hydrogen level H_5, the residual stresses must be reduced to the level indicated by the horizontal section of the curve H_5. Low residual stresses are possible with either a very weak steel or a strong steel that has had a stress relief anneal. Stress relieving is done by holding the weldment at an elevated temperature, see Figure 26-20 and Figure 26-38. At these temperatures the hydrogen can move more freely. The stress relief anneal process can help by dropping the hydrogen level to level H_0.

Hot Cracking

Hot cracks differ from the cold cracks discussed previously. The hot cracks are caused by tearing the metal along partially fused grain boundaries of welds that have

not completely solidified. Unlike those caused by hydrogen, these longitudinal cracks are located in the centers of weld beads. They develop immediately after welding, unlike the delayed nature of hydrogen-induced cracking. In the process of freezing, low-melting materials in the weld metal are rejected as the columnar grains solidify, leaving a high concentration of the low-melting materials where the grains intersect at the center of the weld. These partially melted and weak grain boundaries are stressed while the weld metal shrinks, causing them to rupture.

High sulfur content is most often responsible for hot cracking in steel. It forms a low-melting iron sulfide on the grain boundaries. Hot cracking is more likely to occur in steels that contain higher levels of carbon and phosphorus and in steels that are high in sulfur and low in manganese, **Figure 26-50**.

Severely concave welds may also cause hot cracking because the welds are not as strong. As welds cool, they shrink. If the weld is not thick enough, then when it shrinks it cannot pull the metal in, and so it cracks. Even if the weld is larger, it may crack if the weldment is rigid and cannot be pulled inward by the weld. In these situations, even large welds can have hot cracks.

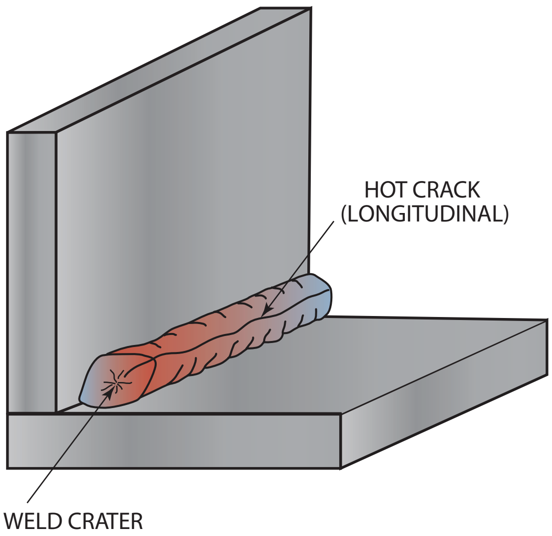


FIGURE 26-50 Hot cracking.

Carbide Precipitation

Stainless steels rely on free chromium for their resistance to corrosion. When carbon is present and the steel is heated to temperatures between approximately 800°F (427°C) and 1500°F (816°C), carbon combines with the chromium to form chromium carbides in the grain boundaries. The formation of chromium carbides depletes the steel of the free chromium needed for protection. Thus, for steels, every effort is made to use low-carbon stainless steel or a special stabilized grade made for welding.

Figure 26-51 illustrates how the chromium in a solution can drop from the nominal 18% in the most commonly

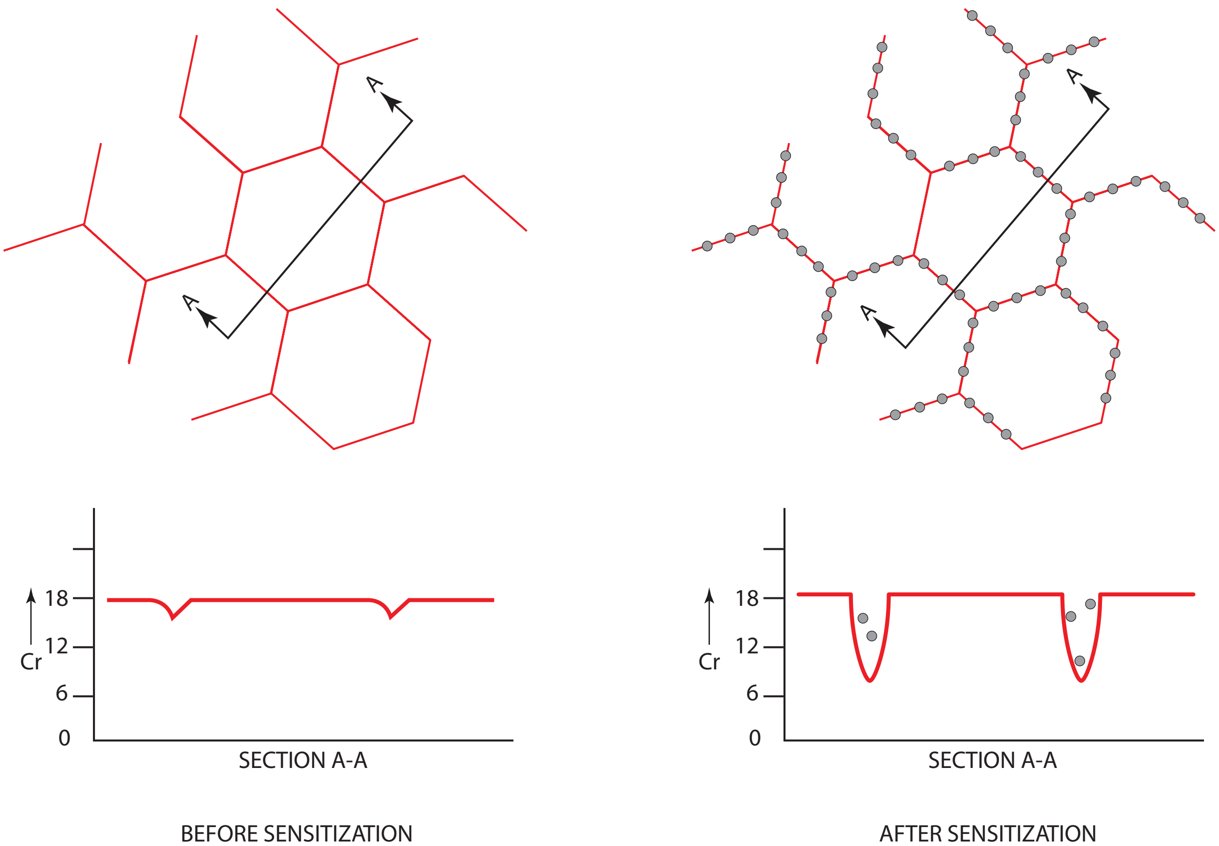


FIGURE 26-51 Depletion of chromium in grain boundaries due to the precipitation of chromium carbide.

used stainless steels to levels well under the 12% needed for even minimal protection. When in contact with corrosive materials, the low chromium grain boundaries can dissolve and the weld can fail, **Figure 26-52**.

Problems are minimized by using very low carbon steel called extra low carbon (ELC) steels. Without carbon, the chromium carbides cannot form. Another way is to tie up the carbon by forming very stable carbides of titanium or columbium. This also prevents chromium carbides from forming. Weld metals are alloyed similarly with low carbon levels or by stabilizing the carbides. Titanium is not generally used for that purpose in electrodes because it is lost in the transfer. Instead, most electrodes are alloyed with columbium to avoid the corrosion problems associated with carbide precipitation.

Carbon dioxide shield gases can cause a similar problem, especially with the ELC grades. These gases supply the carbon that impairs corrosion resistance by depleting the free chromium. The small amounts used in argon to stabilize the arc are often tolerable. But carbon dioxide additions should be avoided unless used with caution and an awareness that problems can develop.

Photo courtesy of George VanderVoort, Buehler, Ltd., Lake Bluff: Illinois

FIGURE 26-52 Microstructure of solution annealed type 304 stainless steel revealing austenite grain boundaries.

Summary

Welding engineers' understanding of science, physics, and metallurgy enables them to design better weldments. Welding engineers must know how the chemical elements that make up a metal alloy will react to changes in physical and thermal stresses. Such stresses are applied to metal products during welding fabrication and as part of their normal service. As metals are thermally cycled, their physical and mechanical properties change. Thermal cycling, of course, occurs every time a metal is welded. Often, as part of a postweld procedure, a welding engineer will have the part heat-treated. Welding engineers use charts and graphs to determine the optimal thermal cycling that will allow for the greatest strength in the weldment design.

You do not have to have as deep of an understanding of the thermal effects on metals as a welding engineer does, but you must know the importance of controlling temperature cycles during welding. Weldment failures may be a result of welder-created problems or welding metallurgical problems. A good understanding of metallurgy will aid you in avoiding welding problems.

Review

1. What gives metals their desirable properties?
2. What is heat?
3. What are the basic units of measure for heat?
4. What is sensible heat?
5. What is latent heat?
6. What does the color of light given off from a hot object indicate?
7. What is a crystal lattice?
8. In steel-making, what is ore combined with in the blast furnace?
9. Why does metal not form into one large, single crystal?
10. What is an alloy?
11. Using Figure 26-18, answer the following questions:
    a. At approximately what temperature does a 70% lead and 30% tin mixture become solid?
    b. What crystal structure is formed first when a 20% lead and 80% tin mixture cools down from a 100% liquid phase?
12. What is a eutectic composition?
13. Using Table 26-3, what are the lowest and highest carbon contents of iron-carbon alloys?

14. Approximately how many degrees wide is the transition range at the 0.1% carbon alloy?

15. Referring to Figure 26-20, what color would low-carbon steel appear when it is in the transition range?

16. Referring to Figure 26-20, what is the approximate temperature of the *lower transformation temperature*?

17. What three factors affect the size and type of crystals formed in an iron-carbon alloy?

18. Referring to Figure 26-20, above what temperature is a 0.1% iron-carbon alloy nonmagnetic?

19. What is the most significant factor that affects how much of an alloying element remains trapped in the iron-carbon crystals?

20. What is known as the critical temperature of iron-carbon alloys?

21. Can a metal have all the mechanical properties at ideal levels? Why or why not?

22. What other properties can a metal's hardness reveal?

23. Which property, brittleness or ductility, will let a metal deform without breaking? Why?

24. What is toughness?

25. What are the common types of strength measurements?

26. What is a major advantage of solid solution–strengthened alloys?

27. What are the three steps in precipitation hardening?

28. How do ferrite and cementite work together to form a strong ductile steel?

29. Why is brine quenching faster than water quenching?

30. What can be done to speed up the quenching rate in any liquid?

31. Why is the formation of martensite a problem when welding on high carbon steels?

32. How can the effects of cold working be removed?

33. How can large-grain crystals be made into smaller sizes?

34. Referring to Figure 26-20, what would the preheat temperature range be for an iron-carbon alloy with 0.6% carbon?

35. Why must the stress-relieving temperature be kept below the critical temperature of the plate?

36. What properties can annealing produce in metals?

37. How long does it take the weld metal to go through its thermal cycle during a weld?

38. What are some sources of hydrogen that can contaminate a weld?

39. How can nitrogen get into an SMA weld?

40. What are some of the problems that oxygen can cause in welds?

41. When do cold cracks develop?

42. What is carbide precipitation?

Chapter 27

Weldability of Metals

OBJECTIVES

After completing this chapter, the student should be able to

- list the methods used to weld most ferrous metals.
- list the methods used to weld four nonferrous metals.
- explain the precautions that must be taken when welding various metals and alloys.
- describe the effects of preheating and postheating on welding.

KEY TERMS

alloy steels

aluminum

cast iron

chromium-molybdenum steel

copper and copper alloys

high-manganese steel

low-alloy steels

magnesium

malleable cast iron

plain carbon steels

stainless steels

steel classification

titanium

tool steel

weldability

INTRODUCTION

All metals can be welded, although some metals require far more care and skill to produce acceptably strong and ductile joints. The term *weldability* has been coined to describe the ease with which a metal can be welded properly. Good weldability means that almost any process can be used to produce acceptable welds and that little effort is needed to control the procedures. Poor weldability means that the processes used are limited and that the preparation of the joint and the procedure used to fabricate it must be controlled very carefully or the weldment will not function as intended.

WELDABILITY

Weldability is defined by the American Welding Society (AWS) as "the capacity of a metal to be welded under the fabrication conditions imposed into a specific, suitably designed structure and to perform satisfactorily in the intended service." Books have been written about this subject. Weldability involves the metallurgy of the metal to be welded and the filler metal, the welding processes, the joint design, the weld preparation, the heat treatments before and after welding, and many other factors, depending on the complexity of the welded system. This chapter does not discuss the selection of methods and procedures for joining difficult-to-weld metals. Those with no previous experience should seek expert help before attempting to weld these metals. Otherwise, they run the risk of failures in service that could physically harm nearby people.

Therefore, an attempt will not be made in this text to cover the weldability of all metals. The welding done in the average school shop is limited to a small number of metals. However, information will be given in this chapter

regarding a number of other metals that will be found in common use in industry.

Thermal Cycling

Most welding processes produce a thermal cycle in which the metals are heated over a range of temperatures. Cooling of the metal to ambient temperatures then follows. The heating and cooling cycles can set up stresses and strains in the weld. Whatever the welding process used, certain metallurgical, physical, and chemical changes also take place in the metal. A wide range of welding conditions can exist for welding methods when joining metals with good weldability. However, if weldability is a problem, then adjustments usually will be necessary in one or more of the following factors:

- Filler metal—If the wrong filler metal is selected, then the weld can have major defects and will not be fit for service. Common defects include porosity, cracks, and filler metal that just will not stick, **Figure 27-1**. The cracks can be in the filler metal or in the base metal alongside the weld. Chapter 28 lists various types of filler metals and their applications. If you are not sure which filler metal to use, then a good general rule is that a little stronger or higher grade can be used successfully, but a lower strength or grade seldom works.
- Shielding atmosphere—Metals such as aluminum, copper, magnesium, and titanium are very easily contaminated by the atmosphere when heated. Therefore, it is important that the correct shielding gas be used in sufficient quantity and with the correct application to protect the molten weld metal.
- Fluxing material—Some metals are reactive to the atmosphere when heated, and others have surface oxides that prevent or limit the filler metal from bonding. Most processes such as SMAW and FCAW have fluxes incorporated with the process, but others such as OFW and TB do not. With these processes, it is as important to select the correct flux as it is to select the correct filler metal.
- Preheat and postheat—Cracking is a common problem when welding on brittle metals such as cast iron or some high-strength alloys. Preheating the part before starting the weld will reduce the stress caused by the weld and will help the filler metal flow. The most commonly used preheat temperature range is between 250°F and 400°F (120°C and 200°C) for most steel, **Table 27-1**. The preheat temperature can be as high as 1200°F (650°C) when welding cast iron. Preheating is required any time the metal to be welded is below 70°F (20°C) because the cold metal quenches the weld. Postheating slows the cool-down rate following welding, which will prevent postweld cracking of brittle metals. Postheating also reduces weld stresses that can result in cracks forming some time after the part is repaired.
- Welding procedure—The size of the weld bead, the number of welds, and the length of the welds all affect the weld. When large welds are needed, it is better to make more small welds than a few large welds. The small welds serve to postheat the weld. They reduce stresses and result in less distortion. Sometimes a series of short back-stepping welds can be made, **Figure 27-2**. For example, these short welds can be used on very brittle metals like cast iron.
- Welding process—The selection of the welding process to be used for any metal, thickness, and application often requires some research. For example, **Table 27-2** is a summary of acceptable welding methods for joining a variety of ferrous metals.

	Plate Thickness (in.)			
ASTM/ AISI	1/4 or less	1/2	1	2 or more
A36	70°F	70°F	70°F	150°F to 225°F
A572	70°	70°	150°	225° to 300°
1330	95°	200°	400°	450°
1340	300°	450°	500°	550°
2315	Room temp.	Room temp.	250°	400°
3140	550°	625°	650°	700°
4068	750°	800°	850°	900°
5120	600°	200°	400°	450°

TABLE 27-1 Recommended Minimum Preheat Temperature for Carbon Steel

FIGURE 27-1 Improper welding technique for filler metal resulting in lack of fusion.

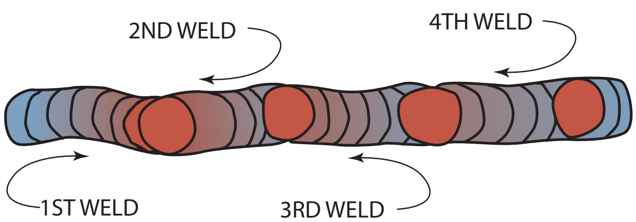


FIGURE 27-2 Welding sequence to produce the minimum weld stresses.

Material	Thick-ness	Joining Process																						
		Welding															Brazing							
		SMAW	SAW	GMAW	FCAW	GTAW	PAW	ESW	EGW	RW	FW	OFW	DFW	FRW	EBW	LBW	TB	FB	IB	RB	DB	IRB	DFB	S
Carbon steel	S	x	x	x		x				x	x	x			x	x	x	x	x	x	x	x	x	x
	I	x	x	x	x	x				x	x	x		x	x	x	x	x	x	x	x	x	x	x
	M	x	x	x	x					x	x	x		x	x	x	x	x	x	x			x	
	T	x	x	x	x			x	x		x	x		x	x			x					x	
Low-alloy steel	S	x	x	x		x				x	x	x	x		x	x	x	x	x	x	x	x	x	x
	I	x	x	x	x	x				x	x		x	x	x	x	x	x	x	x			x	x
	M	x	x	x	x					x	x		x	x	x	x	x	x	x	x			x	
	T	x	x	x	x			x			x	x	x	x	x		x					x		
Stainless steel	S	x	x	x		x	x			x	x		x		x	x	x	x	x	x	x	x	x	x
	I	x	x	x	x	x	x			x	x		x	x	x	x	x	x	x	x			x	x
	M	x	x	x	x		x				x		x	x	x	x	x	x	x	x			x	
	T	x	x	x	x			x			x	x	x	x	x			x					x	
Cast iron	I	x										x					x	x	x	x			x	x
	M	x	x	x	x							x					x	x	x	x			x	x
	T	x	x	x	x							x						x					x	
Nickel and alloys	S	x		x		x	x			x	x	x				x	x	x	x	x	x	x	x	x
	I	x	x	x		x	x			x	x			x	x	x	x	x	x	x			x	x
	M	x	x	x			x				x			x	x	x	x	x					x	
	T	x		x				x			x			x	x			x					x	
Aluminum and alloys	S	x		x		x	x			x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	I	x		x		x				x	x		x	x	x	x	x	x			x		x	x
	M	x		x		x					x			x	x		x	x			x		x	
	T	x		x				x	x		x				x			x					x	
Titanium and alloys	S			x		x	x			x	x		x		x	x		x	x			x	x	
	I			x		x	x				x		x	x		x		x					x	
	M			x		x	x				x		x	x		x		x					x	
	T			x			x				x		x		x	x		x					x	
Copper and alloys	S			x		x	x			x*	x				x		x	x	x	x	x		x	x
	I			x						x				x				x			x		x	x
	M			x						x				x				x					x	
	T			x										x				x					x	
Magnesium and alloys	S			x		x				x					x	x	x	x					x	
	I			x		x				x				x	x	x	x	x					x	
	M			x										x	x	x		x					x	
	T			x											x									
Refractory alloys	S			x		x	x			x	x				x		x	x	x	x		x	x	
	I			x			x			x	x				x		x	x					x	
	M										x													
	T																							

This table is presented as a general survey only. In selecting processes to be used with specific alloys, the reader should refer to other appropriate sources of information.

Legend

Process Code

SMAW—shielded metal arc welding
SAW—submerged arc welding
GMAW—gas metal arc welding
FCAW—flux cored arc welding
GTAW—gas tungsten arc welding
PAW—plasma arc welding
ESW—electroslag welding
EGW—electrogas welding
RW—resistance welding
FW—flash welding
OFW—oxyfuel gas welding
DFW—diffusion welding
FRW—friction welding
EBW—electron beam welding
LBW—laser beam welding
TB—torch brazing
FB—furnace brazing
IB—induction brazing
RB—resistance brazing
DB—dip brazing
IRB—infrared brazing
DFB—diffusion brazing
S—soldering

* Copper requires molybdenum-coated tips.

Thickness

S—sheet: up to 3 mm (1/8 in.)
I—intermediate: 3 to 6 mm (1/8 to 3/4 in.)
M—medium: 6 to 19 mm (1/4 to 3/4 in.)
T—thick: 19 mm (3/4 in.) and up
X—commercial process

TABLE 27-2 Overview of Joining Processes

STEEL CLASSIFICATION AND IDENTIFICATION

SAE Classification Systems

Two primary numbering systems have been developed to classify the standard construction grades of steel, including both carbon and alloy steels. These systems classify the types of steel according to their basic chemical composition. One classification system was developed by the Society of Automotive Engineers (SAE). The other system is sponsored by the American Iron and Steel Institute (AISI).

The numbers used in both systems are now just about the same. However, the AISI system uses a letter before the number to indicate the method used in the manufacture of the steel.

Both numbering systems usually have a four-digit series of numbers. In some cases, a five-digit series is used for certain alloy steels. The entire number is a code to the approximate composition of the steel.

In both **steel classification** systems, the first number often, but not always, refers to the basic type of steel, as follows:

1XXX Carbon
2XXX Nickel
3XXX Nickel chrome
4XXX Molybdenum
5XXX Chromium
6XXX Chromium vanadium
7XXX Tungsten
8XXX Nickel chromium vanadium
9XXX Silicomanganese

The first two digits together indicate the series within the basic alloy group. There may be several series within a basic alloy group, depending on the amount of the principal alloying elements. The last two or three digits refer to the approximate permissible range of carbon content. For example, the metal identified as 1020 would be 1XXX carbon steel with a XX20 0.20% range of carbon content, and 5130 would be 5XXX chromium steel with an XX30 0.30% range of carbon content.

AISI Classification Systems

The letters in the AISI system, if used, indicate the manufacturing process as follows:

- C—Basic open-hearth or electric furnace steel and basic oxygen furnace steel
- E—Electric furnace alloy steel

Table 27-3 shows the AISI and SAE numerical designations of alloy steels.

Unified Numbering System (UNS)

A unified numbering system is currently being promoted for all metals. This system eventually will replace the AISI and other systems.

CARBON AND ALLOY STEELS

Steels alloyed with carbon and only a low concentration of silicon and manganese are known as **plain carbon steels**. These steels can be classified as low-carbon, medium-carbon, and high-carbon steels. The division is based on the percentage of carbon present in the material.

Plain carbon steel is basically an alloy of iron and carbon. Small amounts of silicon and manganese are added to improve their working quality. Sulfur and phosphorus are present as undesirable impurities. All steels contain some carbon, but steels that do not include alloying elements other than low levels of manganese or silicon are classified as plain carbon steels. **Alloy steels** contain specified larger proportions of alloying elements.

The AISI has adopted the following definition of *carbon steel*: "Steel is classified as carbon steel when no minimum content is specified or guaranteed for aluminum, chromium, columbium, molybdenum, nickel, titanium, tungsten, vanadium, or zirconium; and when the minimum content of copper which is specified or guaranteed does not exceed 0.40%; or when the maximum content which is specified or guaranteed for any of the following elements does not exceed the respective percentages hereinafter stated: manganese 1.65%, silicon 0.60%, copper 0.60%." Under this classification will be steels of different composition for various purposes.

Many special alloy steels have been developed and sold under various trade names. These alloy steels usually have special characteristics, such as high tensile strength, resistance to fatigue, corrosion resistance, or the ability to perform at high temperatures. Basically, the ability of carbon steel to be welded is a function of the carbon content, **Table 27-4**. (Other factors to be considered include thickness and the geometry of the joint.) All carbon steels can be welded by at least one method. However, the higher the carbon content of the metal, the more difficult it is to weld the steel. Special precautions must be followed in the welding process.

Low-Carbon, Also Called Mild, Steel

These steels have carbon content of less than 0.30%. These steels can be welded easily by all welding processes. The resulting welds are of extremely high quality. Oxyacetylene welding of these steels can be done by using a neutral flame. Joints welded by this process are of high quality, and the fusion zone is not hard or brittle.

Low-carbon (mild) steels can be welded readily by the shielded metal arc method. The selection of the correct electrode for the particular welding application helps to ensure high strength and ductility in the weld.

13XX	Manganese 1.75
23XX*	Nickel 3.50
25XX*	Nickel 5.00
31XX	Nickel 1.25; chromium 0.65
E33XX	Nickel 3.50; chromium 1.55; electric furnace
40XX	Molybdenum 0.25
41XX	Chromium 0.50 or 0.95; molybdenum 0.12 or 0.20
43XX	Nickel 1.80; chromium 0.50 or 0.80; molybdenum 0.25
E43XX	Same as above, produced in basic electric furnace
44XX	Manganese 0.80; molybdenum 0.40
45XX	Nickel 1.85; molybdenum 0.25
47XX	Nickel 1.05; chromium 0.45; molybdenum 0.20 or 0.35
50XX	Chromium 0.28 or 0.40
51XX	Chromium 0.80, 0.88, 0.93, 0.95, or 1.00
E5XXXX	High carbon; high chromium; electric furnace bearing steel
E50100	Carbon 1.00; chromium 0.50
E51100	Carbon 1.00; chromium 1.00
E52100	Carbon 1.00; chromium 1.45
61XX	Chromium 0.60, 0.80, or 0.95; vanadium 0.12, or 0.10, or 0.15 minimum
7140	Carbon 0.40; chromium 1.60; molybdenum 0.35; aluminum 1.15
81XX	Nickel 0.30; chromium 0.40; molybdenum 0.12
86XX	Nickel 0.55; chromium 0.50; molybdenum 0.20
87XX	Nickel 0.55; chromium 0.50; molybdenum 0.25
88XX	Nickel 0.55; chromium 0.50; molybdenum 0.35
92XX	Manganese 0.85; silicon 2.00; 9262-chromium 0.25 to 0.40
93XX	Nickel 3.25; chromium 1.20; molybdenum 0.12
98XX	Nickel 1.00; chromium 0.80; molybdenum 0.25
14BXX	Boron
50BXX	Chromium 0.50 or 0.28; boron
51BXX	Chromium 0.80; boron
81BXX	Nickel 0.33; chromium 0.45; molybdenum 0.12; boron
86BXX	Nickel 0.55; chromium 0.50; molybdenum 0.20; boron
94BXX	Nickel 0.45; chromium 0.40; molybdenum 0.12; boron

Note: The elements in this table are expressed in percent. Consult current AISI and SAE publications for the latest revisions.

*Nonstandard steel.

TABLE 27-3 AISI and SAE Numerical Designation of Alloy Steels

Common Name	Carbon Content	Typical Use	Weldability
Ingot iron	0.03% max.	Enameling, galvanizing, and deep drawing sheet and strip	Excellent
Low-carbon (mild) steel	0.00% to 0.30%	Welding electrodes, special plate and shapes, sheet, and strip Structural shapes, plate, and bar	Excellent to Good
Medium-carbon steel	0.30% to 0.50%	Machinery parts	Fair*
High-carbon steel	0.50% to 1.00%	Springs, dies, and railroad rails	Poor**

*Preheat and frequently postheat required.

**Difficult to weld without adequate preheat and postheat.

TABLE 27-4 Iron-Carbon Alloys, Uses, and Weldabilities

The gas metal arc and flux cored arc welding processes are used for welding both low- and medium-carbon steels due to the ease of welding and because they prevent contamination of the weld. The high productivity and lower cost make them increasingly popular welding processes.

The gas tungsten arc process is slow and will cause severe porosity in the weld if the steel is not fully degassed (metal that has had all the gas normally dissolved in metal during manufacturing removed). GTAW can make superior welds with a very clear X-ray quality.

Medium-Carbon Steel

The welding of medium-carbon steels, with 0.30% to 0.50% carbon content, is best accomplished by the various fusion processes, depending on the carbon content of the base metal. The welding technique and materials used are dictated by the metallurgical characteristics of the metal being welded. For steels containing more than 0.40% carbon, preheating and subsequent heat treatment generally are required to produce a satisfactory weld. Shielded arc electrodes of the type used on low-carbon steels can be used for welding this type of steel. The use of an electrode with a special low-hydrogen coating may be necessary to reduce the tendency toward underbead cracking.

Medium-carbon steels can be resistance welded. However, special techniques may be required. Other welding methods that produce sound welds on medium-carbon steel include submerged arc welding, thermite welding, pressure gas welding, and spot, flash, and seam welding.

High-Carbon Steel

High-carbon steels usually have a carbon content of 0.50% to 0.90%. These steels are much more difficult to weld than either the low- or medium-carbon steels. Because of the high carbon content, the heat-affected zone can transform to very hard and brittle martensite. The welder can avoid this by using preheat and by selecting procedures that produce high-energy inputs to the weld. Refer to **Figure 27-3** for the preheat temperature for the specific carbon content. The martensite that does form is tempered by postweld heat treatments such as stress-relief anneal. Refer to **Figure 27-4** for the temperature for stress-relief annealing between 1125°F and 1250°F (600°C and 675°C).

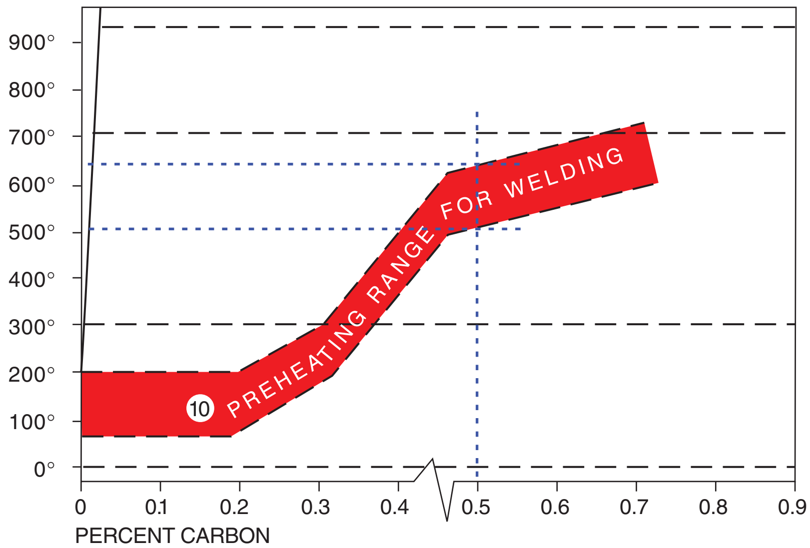


FIGURE 27-3 Preheating range for welding.

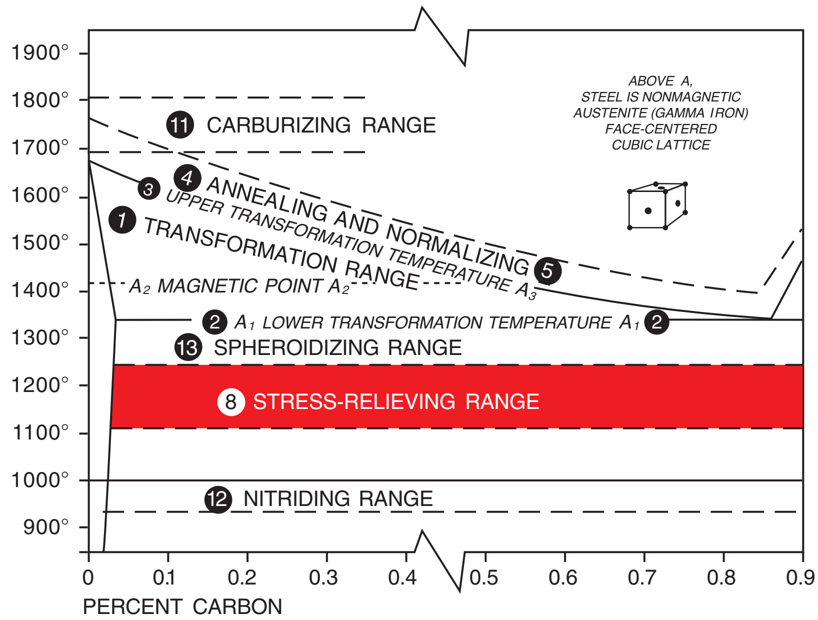


FIGURE 27-4 Stress-relieving range.

In arc welding high-carbon steel, mild steel shielded metal arc electrodes are generally used. However, the weld metal does not retain its normal ductility because it absorbs some of the carbon from the steel. Austenitic steel electrodes can sometimes be used to obtain better ductility in the weld.

Welding on high-carbon steels is often done to build up a worn surface to original dimensions or to develop a hard surface. In this type of welding, preheating or heat treatment may not be needed because of the way in which heat builds up in the part during continuous welding.

Tool Steel

Because **tool steel** has a carbon content from 0.8% to 1.50%, it is very difficult to weld. Gas welding can be used if the material is in the lower carbon ranges. However, when welding tool steel by the gas welding method, the rods selected for welding repairs should have a carbon content matching that of the base metal. Gas welding requires correct flame adjustment and careful manipulation of the flame and rod. Recommended practice is to preheat the metal, followed by slow annealing after the welding. A carburizing or neutral flame is desirable in obtaining a strong weld.

In arc welding tool steels, one of the following procedures should be observed:

- Anneal the parts, preheat and weld with a proper electrode, and then heat-treat to restore the original properties to the metal.
- Preheat the parts and deposit one or more layers on the kerf surfaces of the joint with a covered electrode before depositing the weld beads that tie the joint together. These procedures dilute the carbon content, and the surfaces of the joint can then be more readily welded together.

High-Manganese Steel

High-manganese steel contains 12% or more manganese and a carbon content ranging from 1% to 1.4%. These steels are used for wear resistance in applications involving impact. They are used for items such as power shovels, rock crushers, mine equipment, augers, switch frogs, and so forth.

These alloys are austenitic and, therefore, tough. When inspected, they form a hard martensitic layer on the surface, which provides wear resistance. As martensite develops during work hardness, it reaches a stage where it starts to roll over or it mushrooms, as in the head of a chisel or on the edges of a railroad track. As the components wear in service, they are repaired with electrodes with similar compositions. Care must be taken not to inhale the fumes produced because they are high in manganese.

Martensite is very hard and brittle and must be checked for cracks periodically. If cracks form in the hard martensite layer, then they can move into the softer austenitic below, **Figure 27-5**. There, cracks (like cracks in glass) will continue moving through the part until it breaks. Removing the cracks by welding them up or cutting them out is the only way to prevent them from causing the part to fail.

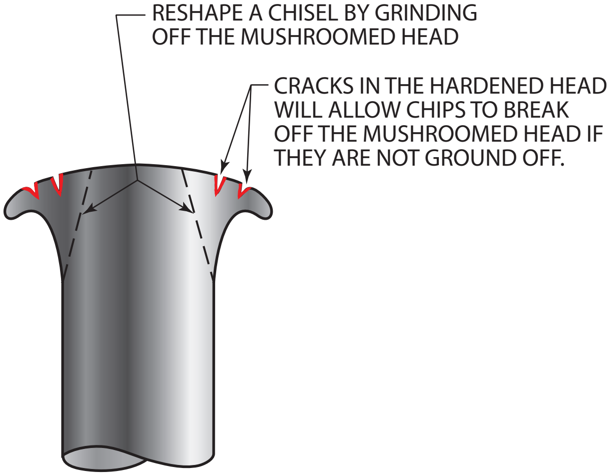


FIGURE 27-5 Work-hardened chisel head.

Low-Alloy, High-Tensile Strength Steels

Low-alloy steels are used increasingly because of requirements for high strength with less weight. These types of steel are readily weldable by all of the common welding processes. The methods and types of electrodes used depend on the end results required. Steel manufacturers can usually supply welding information.

The following types of steel can be found in this class:

- Austenitic manganese
- Chromium alloy
- Carbon-molybdenum
- Chromium-molybdenum
- Chromium-vanadium
- Manganese alloy
- Manganese-molybdenum
- Nickel-chromium
- Nickel-chromium-molybdenum
- Nickel-copper
- Nickel-molybdenum

Other high-strength, low-alloy steels are available under a variety of trade names and are listed in the *Metals Handbook*, published by the American Society for Metals.

STAINLESS STEELS

Stainless steels consist of four groups of alloys: austenitic, ferritic, martensitic, and precipitation hardening. The austenitic group is by far the most common. Its chromium

content provides corrosion resistance, and its nickel content produces the tough austenitic microstructure. These steels are relatively easy to weld, and a large variety of electrode types are available.

Austenitic Stainless Steel

The most widely used stainless steels are the chromium-nickel austenitic types, and these are usually referred to by their chromium-nickel content as 18-8, 25-12, 25-20, and so on. For example, 18-8 contains 18% chromium and 8% nickel, with 0.08% to 0.20% carbon. To improve weldability, the carbon content should be as low as possible. Carbon should not be more than 0.03%, with the maximum being less than 0.10%. Austenitic stainless steels are used for items such as chemical equipment, cooking utensils, food processing equipment, and furnace parts.

Keeping the carbon content low in stainless steel will also help reduce carbide precipitation. Carbide precipitation occurs when alloys containing both chromium and carbon are heated. The chromium and carbon combine to form chromium carbide (Cr_3C_2).

The combining of chromium and carbon lowers the chromium that is available to provide corrosion resistance in the metal. This results in a metal surrounding the weld that will oxidize, or rust. The amount of chromium carbide formed is dependent on the percentage of carbon, the time that the metal is in the critical range, and the presence of stabilizing elements.

If the carbon content of the metal is very low, then little chromium carbide can form. Some stainless steel types have a special low-carbon variation. These low-carbon stainless steels are the same as the base type but with much lower carbon content. To identify the low carbon from the standard AISI number, the *L* is added as a suffix. See examples 304 and 304L, **Table 27-5**.

Chromium carbides Chromium carbides form when the metal is between 800°F and 1500°F (625°C and 815°C). The quicker the metal is heated and cooled through this range, the less time that chromium carbides can form. Because austenitic stainless steels are not hardenable by quenching, the weld can be cooled using a chill plate. The chill plate can be water-cooled for larger welds.

Some filler metals have stabilizing elements added to prevent carbide precipitation. Columbium and titanium are both commonly found as chromium stabilizers. Examples of the filler metals are E310Cb and ER309Cb.

In fusion welding, stainless austenitic steels may be welded by all of the methods used for plain carbon steels.

Ferritic Stainless Steel

Because *ferritic stainless steels* contain almost no nickel, they are cheaper than austenitic steels. They are used for ornamental or decorative applications such as architectural trim and at elevated temperatures such as used for heat exchanging. However, ferritic stainless steels also tend to be brittle unless specially deoxidized. Special high-purity, high-toughness ferritic stainless steels have been developed, but careful welding procedures must be used with them to prevent embrittlement. This means very carefully controlling nitrogen, carbon, and hydrogen.

Martensitic Stainless Steel

Martensitic stainless steels are also low in nickel but contain more carbon than the ferritic. They are used in applications requiring both wear resistance and corrosion resistance. Items such as surgical knives and razor blades are made of them. Quality welding requires very careful control of both preheat and tempering immediately after welding.

Precipitation hardening stainless steels can be much stronger than the austenitic, without losing toughness. Their strength is the result of a special heat treatment used to develop the precipitate. They can be solution-treated prior to welding and given the precipitation treatment after welding.

The closer the characteristics of the deposited metal match those of the material being welded, the better is the corrosion resistance of the welded joint. The following precautions should be noted:

- Any carburization or increase in carbon must be avoided, unless a harder material with improved wear resistance is actually desired. In this case, there will be a loss in corrosion resistance.
- It is important to prevent all inclusions of foreign matter, such as oxides, slag, or dissimilar metals.

In welding with the metal arc process, direct current is more widely used than alternating current. Generally,

Nominal Composition of Stainless Steels						
AISI Type	C	Mn Max	Nominal Composition % Si Max	Cr	Ni	Other
304	0.08 max.	2.0	1.0	18–20	8–12	
304L	0.03 max.	2.0	1.0	18–20	8–12	
316	0.08 max.	2.0	1.0	16–18	10–14	2.0–3.0 Mo
316L	0.03 max.	2.0	1.0	16–18	10–14	2.0–3.0 Mo

TABLE 27-5 Comparison of Standard-Grade and Low-Carbon Stainless Steels

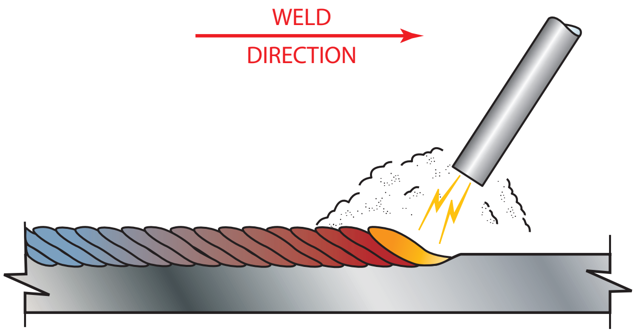


FIGURE 27-6 Backhand or drag angle.

most welding is performed with direct current electrode positive (DCEP), also called reverse polarity.

The diameter of the electrode used to weld steel that is thinner than 3/16 in. (4.8 mm) should be equal to, or slightly less than, the thickness of the metal to be welded.

When setting up for welding, material 0.050 in. (1.27 mm) or less in thickness should be clamped firmly to prevent distortion or warpage. The edges should be butted tightly together. All seams should be accurately aligned at the start. It is advisable to tack weld the joint at short intervals as well as to use clamping devices.

The electrode should always point into the weld in a backhand or drag angle, **Figure 27-6**. Avoid using a figure-8 pattern or excessive side weaving motion such as that used in welding carbon steel. Best results are obtained with a stringer bead with little or very slight weaving motion and steady forward travel, with the electrode holder leading the weld pool at approximately 60° in the direction of travel.

To weld stainless steels, the arc should be as short as possible. **Table 27-6** can be used as a guide.

CHROMIUM-MOLYBDENUM STEEL

Chromium-molybdenum steel is used for high-temperature service and for aircraft parts. It can be welded by the following processes: shielded metal arc, gas tungsten arc, gas metal arc, flux cored, and submerged arc. The welds have a tensile strength of 60,000 psi (49 kg/cm^2) to 80,000 psi (5625 kg/cm^2) as welded. This type of material lends itself to joints in thin sections.

CAST IRON

Cast iron is widely used for engine components such as blocks, heads, and manifolds; for drive components such as transmission cases, gearboxes, transfer cases, and differential cases; and for equipment such as pumps, planters, drills, and pulleys. Cast iron is hard and ridged, which makes it ideal for any size casing or frame that must hold its shape even under heavy loads. For example, if a transmission case were to bend under a load, the gears and shafts inside would bind and stop turning.

All five types of cast iron have high carbon contents, usually ranging from 1.7% to 4%. The most common grades contain approximately 2.5% to 3.5% total carbon. The carbon in cast iron can be combined with iron or be in a free state. As more of the carbon atoms in the cast iron combine with iron atoms, the cast iron becomes harder and more brittle. The five common types of cast iron are as follows:

- *Gray cast iron* is the most widely used type. It contains so much free carbon that a fracture surface has a uniform dark gray color. Gray cast iron is easily welded, but because it is somewhat porous it can absorb oils into the surface, which must be baked out before welding.
- *White cast iron* is the hardest and most brittle of the cast irons because almost all of the carbon atoms are combined with the iron atoms. The surface of a fractured piece of this cast iron looks silvery white and may appear shiny. White cast iron is practically unweldable.
- *Malleable cast iron* is white cast iron that has undergone a transformation as the result of a long heat-treating process to reduce the brittleness. The fractured surface of **malleable cast iron** has a light, almost white, thin rim around the dark gray center. If malleable cast iron is heated above its critical temperature, approximately 1700°F (925°C), the carbon will recombine with the iron, transforming back into white cast iron. Malleable cast iron can easily be welded. To prevent it from reverting back to white cast iron, do not preheat above 1200°F (650°C).
- *Alloy cast iron* has alloying elements such as chromium, copper, manganese, molybdenum, or nickel added to obtain special properties. Various quantities

Metal Thickness		Electrode Diameter		Current (Amperes)	Voltage Open Circuit
in.	mm	in.	mm		
0.050	(1.27)	5/64	(1.98)	25–50	30–35
0.050–0.0625	(1.27–1.58)	3/32	(2.38)	30–90	35–40
0.0625–0.1406	(1.58–3.55)	3/32–1/8	(2.38–3.17)	50–100	40–45
0.1406–0.1875	(3.55–4.74)	1/8–5/32	(3.17–3.96)	80–125	45–50
0.250 and up	(6.35 and up)	3/16	(4.76)	100–175	55–60

TABLE 27-6 Shielded Metal Arc Welding Electrode Setup for Stainless Steel

and types of alloys are added to improve alloy cast iron's tensile strength and heat and corrosion resistance. Almost all grades of alloy cast iron can be easily welded if care is taken to slowly preheat and postcool the part to prevent changes in the carbon and iron structure.

- *Nodular cast iron*, sometimes called ductile cast iron, has its carbon formed into nodules or tiny round balls. These nodules are formed by adding an alloy. Nodular cast iron has greater tensile strength than gray cast iron and some of the corrosion resistance of alloy cast iron. Nodular cast iron is weldable, but proper preheating and postweld cooling temperatures and rates must be maintained or the nodular properties will be lost.

Not all cracks or breaks in cast iron present the same degree of difficulty to making welded repairs. Breaks across ears or tabs do not have nearly as much stresses as a crack in a surface, **Figure 27-7**. Cracks may increase in length when you try to weld them unless you drill a small hole, approximately 1/8 in. (3 mm), at both ends of the crack, **Figure 27-8**.

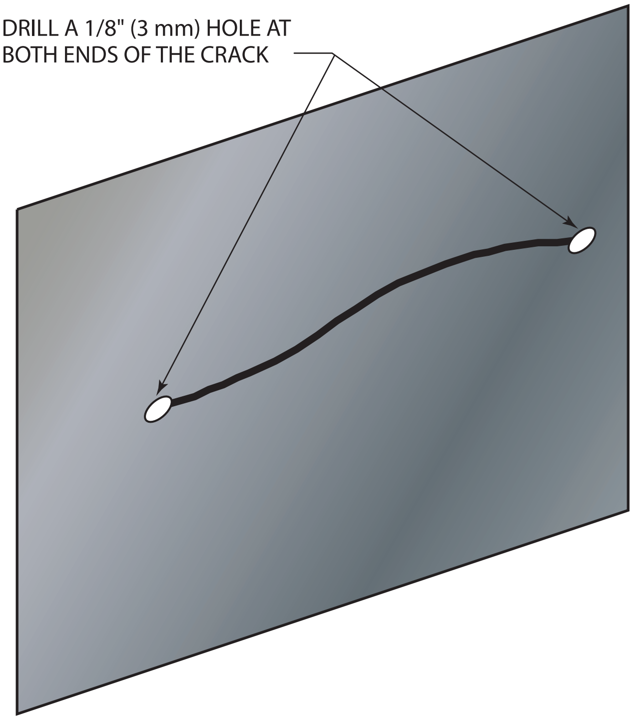


FIGURE 27-8 Stop drill the ends of a crack.

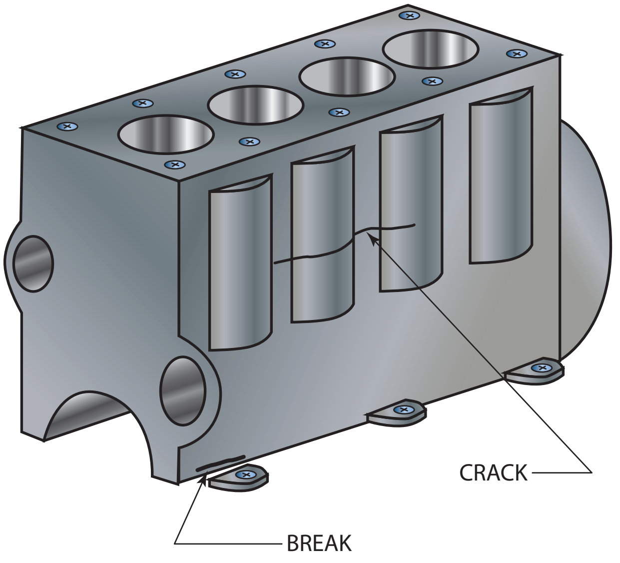


FIGURE 27-7 Cracks on engines can occur in the water jacket due to freezing, and ears can be broken off as a result of accidents or over-lightening of misaligned parts.

Preweld and Postweld Heating of Cast Iron

The major purpose of preheating and postheating of cast iron is to control the rate of temperature change. The level of temperature and the rate of change of temperature affect the hardness, brittleness, ductility, and strength of iron-carbon–based metals such as steel and cast iron, **Table 27-7**.

Preheating the casting before welding reduces the internal stresses caused by the rapid or localized heating resulting from welding, **Table 27-8**. Welding stresses occur because, as metal is heated and cooled, it expands and contracts. Unless the heating and cooling cycles are slow and uniform, stresses within brittle materials will cause them to crack. In some aspects, the brittleness of cast iron is much like that of glass. Both cast iron and glass will crack if they are heated or cooled unevenly or too quickly.

Property	Description
Hardness	The resistance to penetration or shaping by machining or drilling
Brittleness	The ease with which a metal will crack or break apart without noticeable deformation
Ductility	The ability of a metal to be permanently twisted, drawn out, bent, or changed in shape without cracking or breaking
Strength	The ability of a metal to resist deformation or reshaping due to tensile, compression, shear, or torsional forces

TABLE 27-7 Mechanical Properties of Metal

Joining Process	Preheat Temperatures for Weldable Cast Irons		
	Temperature Range	Preferred Temperature	Minimum Temperature
Stick Welding	600°F to 1500°F (315°C to 815°C)	900°F to 1200°F (480°C to 650°C)	400°F (200°C)
Gas Welding	400°F to 1100°F (200°C to 600°C)	500°F (260°C)	400°F (200°C)
Braze Welding	500°F to 900°F (260°C to 480°C)	900°F (480°C)	500°F (260°C)

Note: Maintain the preheat temperature for 30 minutes after it is first reached to allow the core of the casting to reach this temperature.

TABLE 27-8 Welding Should Be Performed at or Above the Preferred Temperature (It can be performed at the minimum temperature, but some hardening and cracking may occur)

Postweld heating changes the rate of cooling. Rapid cooling of a metal from a high temperature is called quenching. The faster an iron-carbon metal is quenched, the harder, more brittle, less ductile, and higher in strength the metal will become. The slow cooling of an iron-carbon metal from a high temperature is called annealing. The slower an iron-carbon metal is cooled from a high temperature, the softer, less brittle, more ductile, and lower in strength the metal will become.

To reduce welding stresses, maintain the casting at the same temperature used for preheat or higher for 30 minutes following welding. The casting should cool slowly over the next 24 hours. Cover the casting to prevent the part from being cooled too rapidly by the surrounding air following welding. A firebrick or heavy metal box can be used to keep cool air away from the casting.

Practice Welding Cast Iron

Because there are a few differences between repairing a break and a crack, the following practices alternate between repairing breaks and cracks in cast iron. For example, other than not clamping the parts together, there would be little difference between using Practice 26-1 for welding a break and for welding a crack. In the field, you can use whichever welding procedure is most appropriate for repairing breaks or cracks.

PRACTICE 27-1

Arc Welding a Cast Iron Break with Preheating and Postheating

Using a properly set-up stick welding station, a gas torch with a heating tip, firebricks, a right angle grinder, ENi electrodes, a C-clamp, a 900°F (482°C) temperature marking crayon, a chipping hammer, a wire brush, a broken piece of gray cast iron, a welding helmet, gas welding goggles, safety glasses, and all other required safety equipment, you are going to repair a cast iron break.

Grind the brake into a V-groove, leaving a 1/8-in. (3-mm) root face on the broken surface, **Figure 27-9**.

NOTE

Because cast iron is brittle, it does not bend before it breaks; therefore, broken parts can usually be fitted back together like the pieces of a puzzle.

Use a C-clamp to hold the broken piece in place. Mark the parts with a 900°F (482°C) temperature marking crayon.

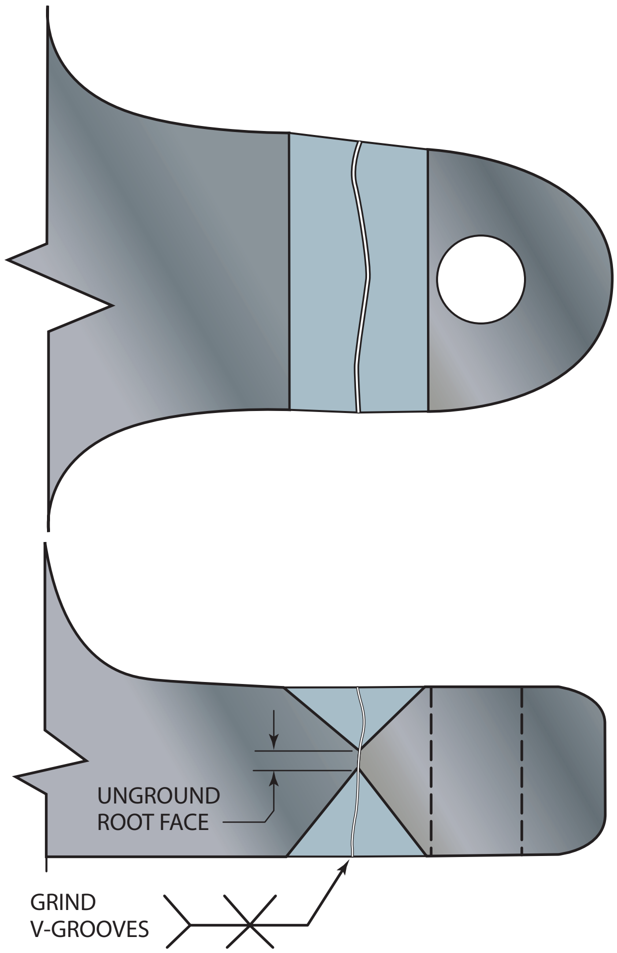


FIGURE 27-9 Grind the V-groove, leaving a small root face so the part can be realigned.

Using a properly lit and adjusted oxyacetylene heating torch, begin preheating the part. Keep the flame moving all around the cast iron part so that it heats evenly. Do not point the flame directly onto the temperature indicator mark or it will turn color before the part is actually preheated. When the temperature mark turns black, the part is properly preheated. With the flame off the part, re-mark the part to check it for proper preheat.

On thick castings, keep the flame on the part for 30 more minutes so the inside of the part is properly preheated.

NOTE

Starting the welds on the ends of the break or crack and welding to the center concentrates the weld stresses in the center of the weld. This reduces the chances of a crack forming at the end of the weld.

Strike an arc and make the first weld bead, starting at one edge. Weld to the center of the break. Break the arc, and chip and wire brush the flux off the weld. Strike another arc on the opposite end of the V-groove and make another weld back to the center of the break, **Figure 27-10**. Turn the part over and make the same two welds on the back side of the break.

NOTE

A number of small welds are better than one or two large welds because the small welds do not have as much stress and are less likely to cause postweld cracking.

Repeat the process of making welds by alternating sides between weld passes until the V-groove is filled to no more than 1/8 in. (3 mm) above the surface.

Build a firebrick box around the part and place the torch so the flame will fill the box and the part can be postweld heated. Keep heating the part for 30 minutes after completing the weld. Close any gaps in the firebrick box and allow the part to cool slowly over the next 24 hours. Turn off the welder and torch set, and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

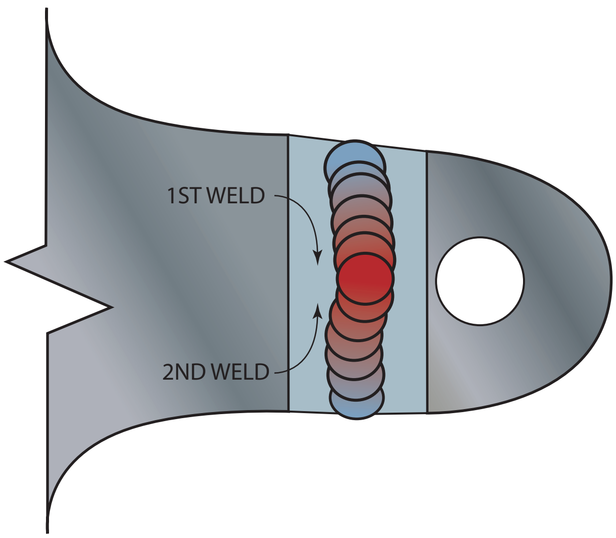


FIGURE 27-10 Start all welding beads on the edge of the break and end them in the middle.

Welding without Preheating or Postheating

Cracks in large castings and castings that are to be repaired in place cannot be preheated and postheated to the desired temperatures but can still be repaired. One method of repairing these cracks is to drill and tap a series of overlapping holes along the crack, **Figure 27-11**. This is an excellent way to repair nonload-bearing cracks like those in the water jacket of an engine. Two-part epoxy patch material can also be used on nonload-bearing cracks. Read and follow the manufacturer instructions and safety rules when using epoxy repair kits.

Cracks in parts that cannot be preheated to the desired level can still be welded, but the welds will be very hard and are more likely to recrack. However, welding cracks in engine blocks, pump housings, and other large expensive castings, even if they might crack again, is more desirable than simply buying a new part. The new cracks that might form may even be small enough to be patched with epoxy.

PRACTICE 27-2

Arc Welding a Cast Iron Crack without Preheating or Postheating

Using a properly set-up stick welding station, a gas torch with a heating tip, firebricks, a portable drill with 1/8-in. (3-mm) drill bit, a right angle grinder, ENi electrodes, a chipping hammer, a wire brush, a cracked piece of gray cast iron, a welding helmet, gas welding goggles, safety glasses, and all other required safety equipment, you are going to repair a cast iron crack.

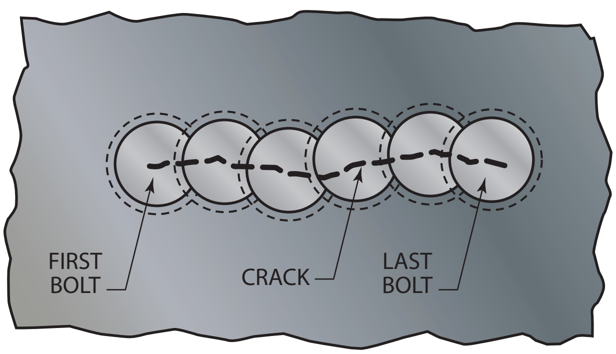


FIGURE 27-11 A crack in cast iron can be plugged by drilling and tapping overlapping holes. Each bolt overlaps the previous bolt. Only the last one must have a locking compound to prevent it from loosening.

Locate the ends of the crack and drill stop the crack by drilling 1/8-in. (3-mm) holes at both ends of the crack. Use the edge of the grinding disk to cut a V- or U-groove into the crack.

NOTE

Even though the part cannot be preheated to the desired level, it cannot be welded cold. It must be heated to at least 75°F (24°C) or higher before starting to weld. Engine blocks can be preheated by letting them run for a short time until they are hot.

Strike the arc on the casting just before the end of the crack and make a 1-in. (25-mm)-long weld, **Figure 27-12**. Stop the weld and repeat the process starting at the other end of the crack. Chip and wire brush the welds.

NOTE

A series of short welds will create less stress than one large weld. The small welds are less likely to crack.

NOTE

The next series of welds that are made to close the crack are done in a back-stepping sequence. Back-stepping welds are short welds that start ahead of the ending point of the first weld and go back to the end of the first weld. Back-stepping welds are used because they reduce weld stresses and are less likely to crack.

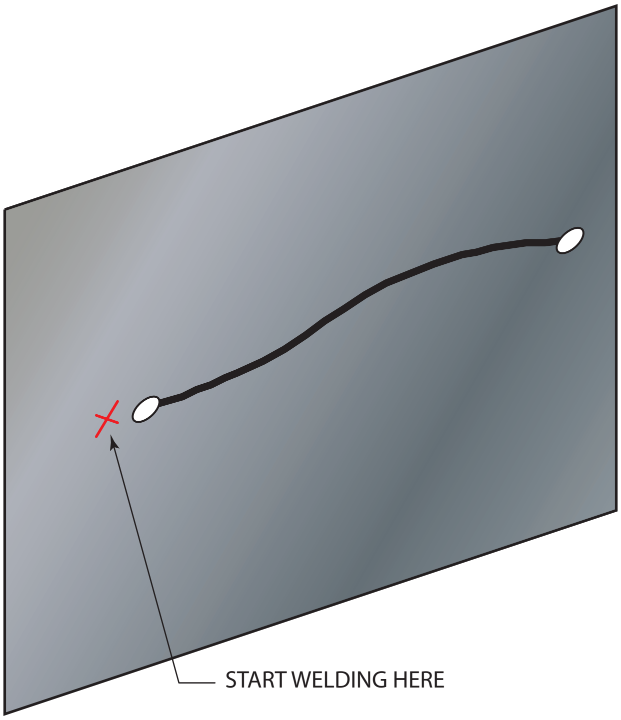


FIGURE 27-12 Start the weld on the casting's surface outside of the crack.

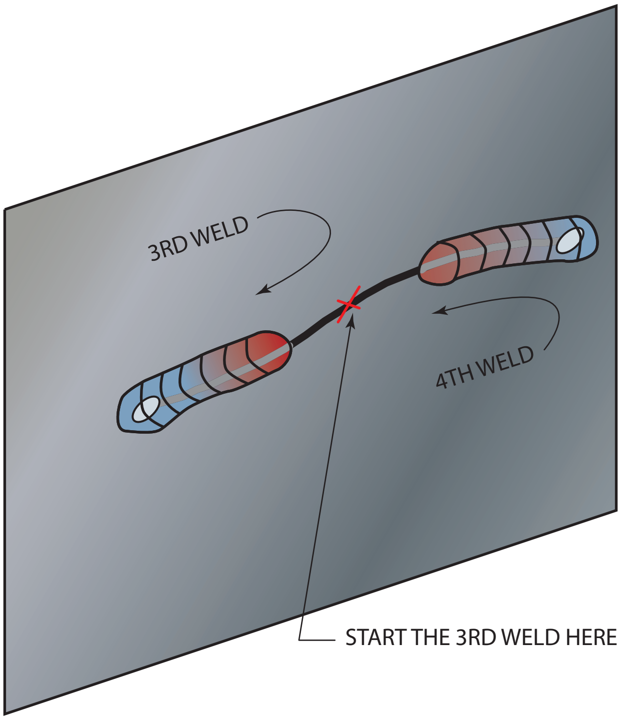


Figure 27-13 After both ends have been welded, use a back-step welding process to complete the weld.

Start the third weld approximately 1 in. (25 mm) in front of the end of the first weld and move back to the end of the first weld, **Figure 27-13**. Vigorously chip the slag off the weld immediately after the arc stops. This both cleans the weld and mechanically works the weld surface, called peening, to reduce weld stresses. Repeat the back-step sequence of welding and peening until the crack is completely covered with welds. Turn off the welder and torch set, and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 27-3

Gas Welding a Cast Iron Break with Preheating or Postheating

Using a properly set-up gas torch with welding and heating tips, firebricks, a right angle grinder, cast iron gas welding rods, high-temperature cast iron welding flux, a C-clamp, a 500°F (260°C) temperature marking crayon, a chipping hammer, a wire brush, a broken piece of gray cast iron, gas welding goggles, safety glasses, and all other required safety equipment, you are going to repair a cast iron break.

Grind the break into a V-groove, leaving a 1/8-in. (3-mm) root face on the broken surface. Use a C-clamp to hold the broken piece in place. Mark the parts with a 500°F (260°C) temperature marking crayon. Using a properly lit and adjusted oxyacetylene heating torch, begin preheating the part. Keep the flame moving all around the cast iron part so that it heats evenly. Do not point the flame directly onto the

temperature indicator mark or it will turn color before the part is actually preheated. When the temperature mark turns black, the part is properly preheated. With the flame off the part, re-mark the part to check it for proper preheat.

On thick castings, keep the flame on the part for 30 more minutes so that the inside of the part is properly preheated. Flux the end of the cast iron filler rod by heating it with the torch and dipping it into the flux. As the weld progresses, occasionally re-dip the end of the filler rod back into the flux so new flux can be added to the weld. Start welding at one end of the crack. The molten weld pool formed by cast iron is not bright and shiny like that formed on mild steel. The cast iron molten weld pool looks dull and a little lumpy. As the weld progresses, move the tip of the filler rod around in the molten weld pool to keep it stirred up and to make it flatter.

Fill the crater at the end of the weld with a little extra filler metal. Turn the part over and make the same weld on the back side of the break. Build a firebrick box around the part and place the torch so the flame will fill the box and so the part can be postweld heated. Keep heating the part for 30 minutes after completing the weld.

Close any gaps in the firebrick box and allow the part to cool slowly over the next 24 hours. Turn off the torch set and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 27-4

Braze Welding a Cast Iron Crack with Preheating or Postheating

Using a properly set-up gas torch with welding and heating tips, firebricks, a right angle grinder, BRCuZn rods, brazing flux, a C-clamp, a 900°F (480°C) temperature marking crayon, a chipping hammer, a wire brush, a cracked piece of gray cast iron, gas welding goggles, safety glasses, and all other required safety equipment, you are going to repair a cast iron crack.

Locate the ends of the crack and drill stop the crack by drilling 1/8-in. (3-mm) holes at both ends of the crack. Use the edge of the grinding disk to cut a V- or U-groove into the crack. Mark the parts with a 900°F (480°C) temperature marking crayon. Using a properly lit and adjusted oxyacetylene heating torch, begin preheating the part. Keep the flame moving all around the cast iron part so that it heats evenly. Do not point the flame directly onto the temperature indicator mark or it will turn color before the part is actually preheated. When the temperature mark turns black, the part is properly preheated. With the flame off the part, re-mark the part to check it for proper preheat. On thick castings, keep the flame on the part for 30 more minutes so that the inside of the part is properly preheated.

Flux the end of the brazing rod by heating it with the torch and dipping it into the flux. As the weld progresses, occasionally re-dip the end of the filler rod back into the flux so new flux can be added to the weld. Start welding at one end of the crack. Heat the groove until it is dull red, to approximately 1800°F (980°C). Touch the tip of the brazing rod into the groove occasionally to test it for the proper brazing temperature. When the braze metal begins to flow, move the tip of the rod around in the molten braze pool to help it wet the surface of the groove. When the braze reaches the end of the groove, add a little extra fill to the crater at the end of the braze weld. Turn the part over and make the same weld on the back side of the break.

Build a firebrick box around the part and place the torch so that the flame will fill the box and the part can be postweld heated. Keep heating the part for 30 minutes after completing the weld. Close any gaps in the firebrick box and allow the part to cool slowly over the next 24 hours. Turn off the torch set and clean your work area when you are finished welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

NONFERROUS METALS

Metals that are not primarily composed of iron are known as nonferrous metals. Each nonferrous metal has its unique physical and metallurgical property that must be considered when selecting a welding procedure. The most common nonferrous metals that welders are asked to weld are: copper and copper alloys, aluminum, titanium, and magnesium.

Copper and Copper Alloys

There are many different types of copper alloys. Copper is often alloyed with other metals such as tin, zinc, nickel, silicon, aluminum, and iron. **Copper and copper alloys** can be joined by most of the commonly used methods such as gas welding, arc welding, resistance welding, brazing, and soldering.

For many years, the successful welding of copper was considered impractical. Too much distortion resulted when using a gas torch. That heat source was barely able to melt the metal due to its high thermal conductivity. The more highly intense electric arc overcomes that difficulty.

When you are welding copper, the welding current should be considerably higher than when welding steel. On copper 1/8 in. (3 mm) or more in thickness, the current should not be more than 140 A. The preheat should be 500°F (260°C). By using this method of welding copper, satisfactory results can be obtained for the following factors: economy, speed, ductility, strength, and freedom from distortion. However, the copper must not be electrolytic because excessive amounts of gas in the metal increase porosity.

Aluminum Weldability

One of the characteristics of **aluminum** and its alloys is that it has a great affinity for oxygen. Aluminum atoms combine with oxygen in the air to form a high-melting-point oxide that covers the surface of the metal. This feature, however, is the key to the high resistance of aluminum to corrosion. It is because of this resistance that aluminum can be used in applications where steel is rapidly corroded.

Pure aluminum melts at 1200°F (650°C). The oxide that protects the metal melts at 3700°F (2037°C). Because

the oxide melts at a temperature approximately 2500°F (1370°C) higher than the aluminum itself, the oxide must be cleaned from the metal before welding can begin.

When the GMA welding process is used, the stream of inert gas covers the weld pool, excluding all air from the weld area. This prevents re-oxidation of the molten aluminum. GMA welding does not require a flux.

Aluminum can be arc welded using aluminum welding rods. These rods must be kept in a dry place because the flux picks up moisture easily. Because aluminum melts so easily, use a piece of clean steel plate as a backing to weld on thin sections. The steel backing plate can support the root of the weld without the aluminum weld sticking to the steel plate. Thick aluminum casting must be preheated to approximately 400°F (200°C) before welding. The preheating helps the weld flow and reduces weld spatter.

Aluminum has high thermal conductivity. Aluminum and its alloys can rapidly conduct heat away from the weld area. For this reason, it is necessary to apply the heat much faster to the weld area to bring the aluminum to the welding temperature. Therefore, the intense heat of the electric arc makes this method best suited for welding aluminum.

When aluminum welds solidify from the molten state, they will shrink approximately 6% in volume. The stress that results from this shrinkage may create excessive joint distortion unless allowances are made before joining the metal. Cracking can occur because the thermal contraction is approximately two-times that of steel. The heated parent metal expands when welding occurs. This expansion of the metal next to the weld area can reduce the root opening on butt joints during the process. The contraction that results upon cooling, plus the shrinkage of the weld metal, creates tension and increases cracking.

The shape of the weld groove and the number of beads can affect the amount of distortion. Less distortion occurs with two-pass square butt welds. Other factors that have an influence on the weld are the speed of welding, the use of properly designed jigs and fixtures to support the aluminum while it is being welded, and tack welding to hold parts in alignment.

Titanium

Titanium is a silver-gray metal weighing approximately half as much as steel or approximately one and one-half times as much as aluminum. Two of the most important properties of titanium are its extremely high strength-to-weight ratio (in alloy form) and its generally excellent corrosion resistance. Titanium alloys, unlike most other light metals, retain their strength at temperatures up to approximately 800°F (426°C).

Pure titanium is comparatively soft and weak. It is very difficult to refine. Commercially pure titanium contains trace impurities that increase the strength considerably and at the same time cause a loss in ductility. Alloy combinations currently in use contain assortments of tin, chromium, iron, aluminum, and vanadium.

The success of welding titanium depends on complete shielding from the atmospheric gases oxygen, nitrogen, and hydrogen and from sources of carbon. The inert gas welding process seems to be the best method of welding this metal. Shielding gases used are argon, helium, or a combination of the two. It is preferable to perform the welding in a closed chamber.

When welding titanium, the joint must be clean and have no traces of contamination. Clean filler metal and perfect shielding are required to eliminate the porosity and embrittlement that can be produced during welding.

Magnesium

Magnesium is an extremely light metal with a silver-white color. The weight of magnesium is one-fourth that of steel and approximately two-thirds that of aluminum. Its melting point is 1202°F (650°C). Magnesium has considerable resistance to corrosion and compares favorably with some aluminum alloys in this respect.

Magnesium must be alloyed with other elements to provide the necessary strength for most applications. Common alloying elements include zinc, aluminum, manganese, zirconium, and the rare earths. Magnesium alloys may be classified as wrought or casting types. Sheet, plate, and extrusions are part of the first group.

The alloy designations for magnesium consist of one or two letters that represent the alloying elements. The alloying percentages are next listed in the designation. A letter is also added after the alloying percentages. One example is the ASTM designation AZ91C. This indicates an alloy of 9% aluminum and 1% zinc. The letter following the designation is defined as follows:

- A—aluminum
- C—copper
- E—rare earths
- H—thorium
- K—zirconium
- M—manganese
- Z—zinc

The temper designation is the same as that used for aluminum. Wrought alloys are used to a great extent because of their properties of high strength, ductility, formability, and toughness.

Magnesium can be welded in somewhat the same manner as aluminum. The most widely used processes are GTA and GMA. Spot, seam, and mechanized resistance welding processes can also be used to weld magnesium on a production basis. Spot and seam welding applications consist of welding sheets and extrusions to thicknesses up to 3/16 in. (approximately 4.8 mm).

REPAIR WELDING

Repair, or maintenance, welding is one of the most difficult types of welding. Some of the major problems include preparing the part for welding, identifying the material, and selecting the best repair method.

The part is often dirty, oily, and painted, and it must be cleaned before welding. There are many hazardous compounds that might be part of the material on the part. These compounds may or may not be hazardous on the part, but when they are heated or burned during welding, they can become life-threatening.

CAUTION

It is never safe to weld on any part that has not been cleaned before welding. All surface contamination must be removed before welding to prevent the possibility of injuring your health from exposure to materials released during welding. Some chemicals can be completely safe until they are exposed to the welding. The smoke or fumes they produce can be an irritant to the skin or eyes and can be absorbed through the skin or lungs. If you are exposed to an unknown contaminant, get professional help immediately.

Contamination can be removed by sandblasting, grinding, or using solvents. If a solvent is used, be sure it does not leave a dangerous residue. Clean the entire part if possible or a large enough area so that any remaining material is not affected by the welding.

Before the joint can be prepared for welding, you must try to identify the type of metal. There are several ways to determine metal type before welding. One method is to use a metal identification kit. These kits use a series of chemical analyses to identify the metal. Some kits not only can identify a type of metal but also can tell the specific alloy.

Another way to identify metal is to look at its color, test for magnetism, and do a spark test. The spark test should be done using a fine grinding stone. With experience, it is often possible to determine specific types of alloys with great accuracy. The sparks given off by each metal and its alloy are so consistent that the U.S. Bureau of Mines uses a camera connected to a computer to identify metals. Microprocessor-controlled testing units are used to identify metals for recycling. For the beginner it is best if you use samples of a known alloy and compare the sparks to your unknown. The test specimen and the unknown should be tested using the same grinding wheel and the same force against the wheel.

EXPERIMENT 27-1

Identifying Metal Using a Spark Test

In this experiment you will be working in a small group to identify various metals using a spark test, **Figure 27-14**. You will need to use proper eye safety equipment, a grinder, several different known and unknown samples of metal, and a pencil and paper to identify the unknown metal samples. Starting with the known samples, make several tests and draw the spark patterns as described in the following paragraphs. Next, test the unknown samples and compare the drawings with the drawings from the known samples. See how many of the unknowns you can identify.

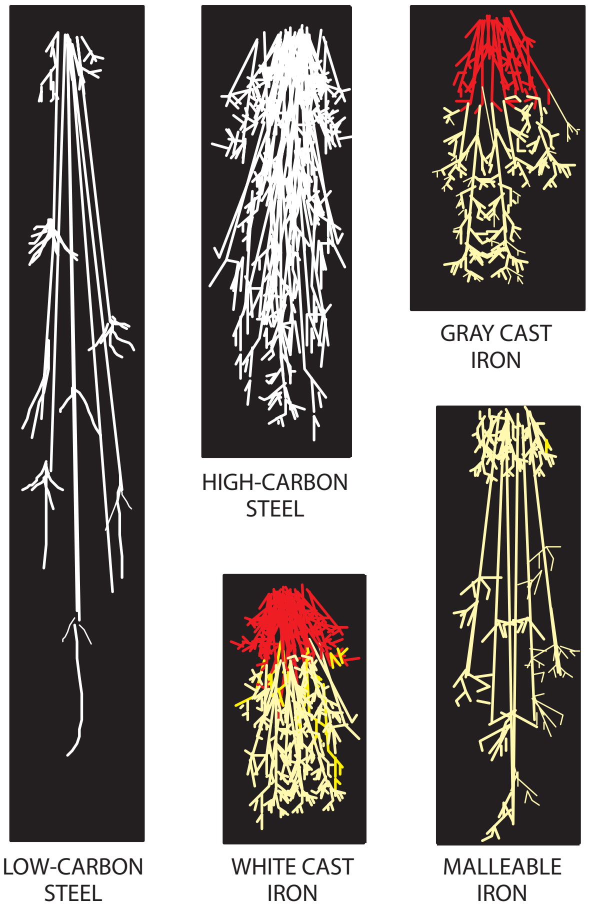


FIGURE 27-14 Spark test patterns for five common metals.

There are several areas of the spark test pattern that you must observe carefully, **Figure 27-15(1)**. The first area is the grinding stone. Are there sparks that are being carried around the wheel, or are all of the sparks leaving the wheel, **Figure 27-15(2).**

The next area is immediately adjacent to the wheel where the spark stream leaves the wheel. Note the color of this area; it may vary from white to dull red. Also note the stream to see if the sparks are small, medium, or large and whether the column of sparks is tightly packed or spread out. Draw a sketch of what the spark stream looks like here, **Figure 27-15(3)**.

As the spark stream moves away from the wheel a few inches it will begin to change. This change may be in color, speed of the sparks, or size of the sparks; the sparks may divide into smaller, separate streams, explode in a burst of tiny fragments, or just stop glowing, **Figure 27-15(4)**. Sketch these changes you see in the sparks.

When the sparks end they may simply stop glowing, change color, change shape, explode, or divide into smaller parts, **Figure 27-15(5)**. Sketch these changes you see in the sparks.

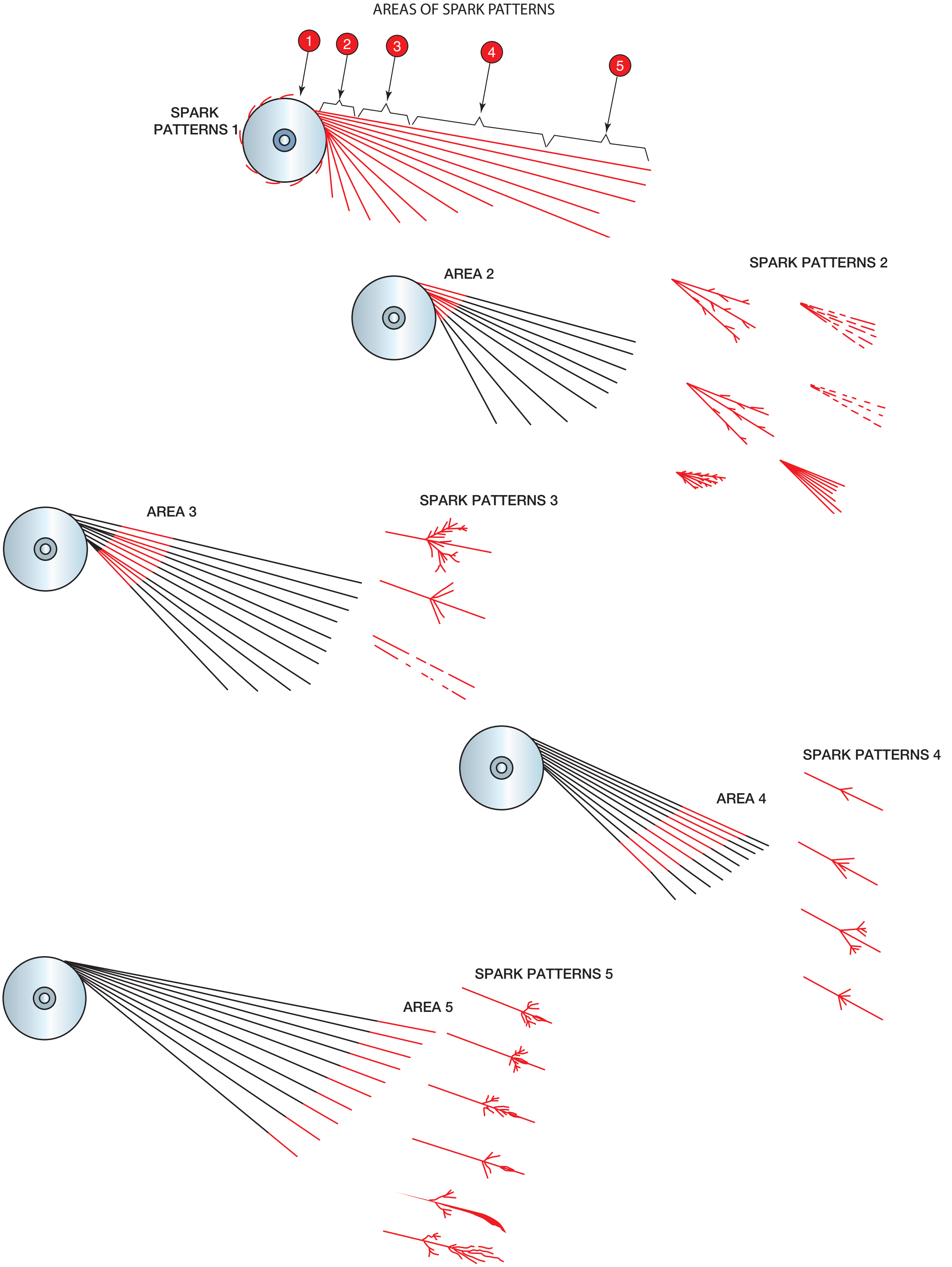


FIGURE 27-15 Spark test.

	Thickness in inches			
Metal	1/8–1/4	1/4–1/2	1/2–1	Over 1
Mild steel	Square	V	V	V
Aluminum	Square	U	U	U
Magnesium	U	U	U	U
Stainless steel	Square	V	V	V
Cast iron	V	V	U	U

TABLE 27-9 Groove Shapes

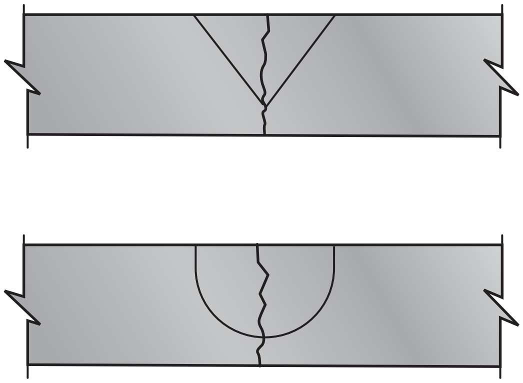


FIGURE 27-16 A small section of the bottom of the break is left so the parts can be realigned.

Repeat this experiment with other types of metal as they become available. Once the type of metal to be repaired is determined, to the best of your ability decide on the type of weld groove that is needed. Some breaks may need to be ground into a V- or U-groove, and others may not need to be grooved at all, **Table 27-9**.

Often thin sections of most metals can be repaired without the need for the break to be grooved. Thicker sections of most metals will be easier to repair if the crack is ground into a groove. To help in the realignment of the part, it is a good idea to leave a small part of the crack unground so that it can be used to align the parts, **Figure 27-16**.

After the part is ready to be welded, a test tab can be welded onto the part. This test tab should be welded in a spot that will not damage the part. Once the tab is welded on, it can be broken off to see if the weld will hold, **Figure 27-17**. If the test tab shows good strength, then the repair should continue. If the test tab fails, then a new welding procedure should be tried.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

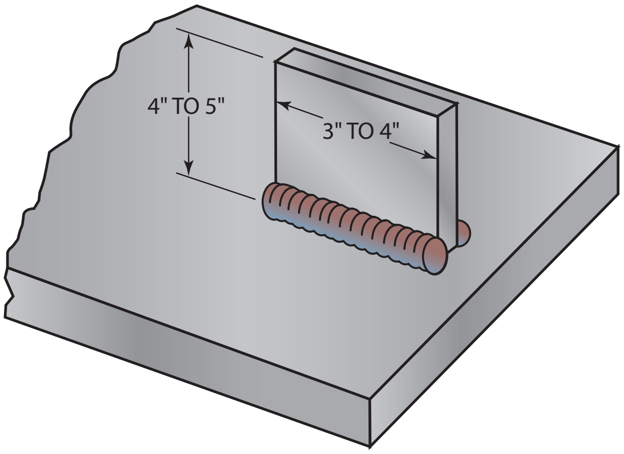


FIGURE 27-17 Tab test.

Summary

All metals are weldable. The only limitation in the fabrication and repair of parts is the cost to our customers. It takes a skilled maintenance and repair welder with an understanding of all of the various characteristics of the metals and types of welding to fix worn or damaged parts. Being able to recognize the differences among the various classifications of metal will allow you to select the most appropriate welding repair procedure. Because of the complexity of this process, you may often be required to research through the original manufacturer of the equipment the types of processes and materials used in the weldment's construction.

Things change, so sometimes once a part is placed in service there is a need to change the welding procedures used in the part's original construction for the repair welding. In addition, the original manufacturer may no longer have the welding procedure. To make a successful weld in such cases, the welder must be able to establish a new welding procedure. As part of your welding procedure you may perform tests to enhance the longevity of your repairs. Your welding experience will help you to be more efficient in producing the new welding procedure.

The diversity and challenges offered by repair and maintenance welding make it one of the most interesting welding jobs available. It can be one of the best paying jobs for a skilled welder.

Review

1. What is meant when a metal is said to have good weldability?
2. What does the term *weldability* involve?
3. What properties of a metal can be affected by the choice of welding process?
4. Referring to Table 27-2, what commercial joining process can be used to weld 1-in. (25-mm)-thick cast iron?
5. Referring to Table 27-2, what commercial joining process can be used to braze sheet stainless steel?
6. Referring to Table 27-2, what types of metals can electrogas welding be used to join?
7. What two organizations have developed systems for classifying standard construction grades of steel?
8. Explain the steel classification number 1030.
9. Referring to Table 27-3, what is the composition of the metal identified as 44XX?
10. What is the maximum allowable percentage of manganese in carbon steel as defined by the AISI classification for carbon steel?
11. According to Table 27-4, at what level of carbon content does weldability become poor?
12. What factors other than carbon affect a steel's ability to be welded?
13. Why would some low-carbon steels have severe porosity when welded with the GTA welding process?
14. What must be done to steels before welding and after welding if they contain more than 0.40% carbon?
15. Why are high-carbon steels preheated before welding?
16. Explain how to weld tool steel with the oxyfuel process.
17. Why must cracks in the martensite layer of high-manganese steels be removed?
18. What properties do chromium and nickel produce in stainless steels?
19. What problems can occur to stainless steel as it is allowed to form carbide precipitation during welding?
20. Why should stainless steel not be held at a temperature between 800°F and 1500°F (425°C and 815°C)?
21. What are the different uses for the three types of stainless steels?
22. Referring to Table 27-6, what diameter SMA welding electrode should be used for 1/4-in. (6-mm)-thick stainless steel?
23. Why must cast iron weld metal be ductile?
24. Why should copper be welded with high currents and preheated?
25. Why can't aluminum oxide be melted off aluminum?
26. Why are aluminum welds likely to cause distortion and cracking?
27. What alloying elements are added to titanium to give it its strength?
28. What do the letters and numbers in a magnesium identification stand for?
29. How can a part be cleaned before it is welded?
30. How can a spark test be used to identify metals?

Chapter 28
Filler Metal Selection

OBJECTIVES

After completing this chapter, the student should be able to

- explain how and when to use each type of filler metal.
- select the best filler metal to fit a specific welding job.
- list the forms filler metals come in.
- explain the significance of the filler metal prefixes.
- explain how to interpret the standard filler metal numbering systems.
- describe the effects alloys have on ferrous metals.

KEY TERMS

alloying elements
arc blow
brazing (B)
carbon equivalent (CE)
Charpy V-notch
composite electrode (EC)
core wire
electrode (E)
electrode and/or rod (RB)
electrode or rod (ER)
elongation
fast freezing
filler metals
flux (F)
flux cover
heat-affected zone (HAZ)
hydrogen embrittlement
insert (IN)
minimum tensile strength
tungsten electrode (EW)
yield point

INTRODUCTION

Manufacturers of **filler metals** may use any one of a variety of identification systems. There is not a mandatory identification system for filler metals. Manufacturers may use their own numbering systems, trade names, color codes, or a combination of methods to identify filler metal. They may voluntarily choose to use any one of several standardized systems.

The most widely used numbering and lettering system is the one developed by the American Welding Society (AWS). Other numbering and lettering systems have been developed by the American Society for Testing and Materials (ASTM) and the American Iron and Steel Institute (AISI). A system of using colored dots has also been developed by the National Electrical Manufacturers Association (NEMA).

Some manufacturers have produced systems that are similar to the AWS system. Most major manufacturers include both the AWS identification and their own identification on the box, on the package, or directly on the filler metal.

Information that pertains directly to specific filler metals is readily available from most electrode manufacturers. The information given in charts, pamphlets, and pocket electrode guides is specific to their products and may or may not include standard AWS tests, terms, or classifications within their identification systems.

The AWS publishes a variety of books, pamphlets, and charts showing the minimum specifications for filler metal groups. It also publishes comparison charts that include all of the information manufacturers provide the AWS regarding their filler metals. Literature on filler metal specifications and filler metal comparisons may be obtained directly from the AWS or located on the electrode manufacturer's web site.

The AWS classification system is for minimum requirements within a grouping. Filler metals manufactured within a grouping may vary but may still be classified under that grouping's classification.

A manufacturer may add elements to the metal or flux, such as more arc stabilizers. When one characteristic is improved, another characteristic may also change. The added arc stabilizer may make a smoother weld with less penetration. Other changes may affect the strength and ductility or other welding characteristics.

Because of the variables within a classification, some manufacturers make more than one type of filler metal that is included in a single classification. This and other information may be included in the data supplied by manufacturers.

MANUFACTURERS' ELECTRODE INFORMATION

The type of information given by different manufacturers ranges from general information to technical, chemical, and physical information. A mixture of different types of information may be given.

General information given by manufacturers may include some or all of the following: welding electrode manipulation techniques, joint design, prewelding preparation, postwelding procedures, types of equipment that can be welded, welding currents, and welding positions.

Understanding the Electrode Data

Technical procedures, physical properties, and chemical analysis information given by manufacturers include the following:

- Number of welding electrodes per pound
- Number of inches of weld per welding electrode
- Welding amperage range setting for each size of welding electrode
- Welding codes for which the electrode can be used
- Types of metal that can be welded
- Ability to weld on rust, oil, or paint
- Weld joint penetration characteristics
- Preheating and postheating temperatures
- Weld deposit physical strengths: ultimate tensile strength, yield point, yield strength, elongation, and impact strength
- Percentages of alloys such as carbon, sulfur, phosphorus, manganese, silicon, chromium, nickel, molybdenum, and other alloys

The information supplied by the manufacturer can be used for a variety of purposes, including the following:

- Estimates of the pounds of electrodes needed for a job
- Welding conditions under which the electrode can be used—for example, on clean or dirty metal
- Welding procedure qualification information regarding amperage, joint preparation, penetration, and welding codes
- Physical and chemical characteristics affecting the weld's strengths and metallurgical properties

Data Resulting from Mechanical Tests

Most of the technical information supplied is self-explanatory and easily understood. The mechanical properties of the weld are given as the results of standard tests. The following are some of the standard tests and the meaning of each test:

- **Minimum tensile strength**, psi (N/mm^2)—the load in pounds (megapascal [MPa]) that would be required to break a section of sound weld that has a cross-sectional area of 1 sq in.
- **Yield point**, psi (N/mm^2)—the point in low- and medium-carbon steels at which the metal begins to stretch when force (stress) is applied after which it will not return to its original length
- **Elongation**, percent in 2 in. (50 mm)—the percentage that a 2-in. (50-mm) piece of weld will stretch before it breaks
- **Charpy V-notch**, ft-lb (m-kg)—the impact load required to break a test piece of weld metal; this test may be performed on metal below room temperature at which point it may be more brittle

Data Resulting from Chemical Analysis

Chemical analysis of the weld deposit may also be included in the information given by manufacturers. It is not so important to know what the different percentages of the alloys do, but it is important to know how changes

in the percentages of the alloys affect the weld. Chemical composition can easily be compared from one electrode to another. The following are the major elements and the effects of their changes on the iron in carbon steel:

- Carbon (C)—As the percentage of carbon increases, the tensile strength increases, the hardness increases, and ductility is reduced. Carbon also causes austenite, a strong, hard, and brittle form of steel to form.
- Sulfur (S)—It is usually a contaminant, and the percentage should be kept as low as possible below 0.04%. As the percentage of carbon increases, sulfur can cause hot shortness and porosity.
- Phosphorus (P)—It is usually a contaminant, and the percentage should be kept as low as possible. As the percentage of phosphorus increases, it can cause weld brittleness, reduced shock resistance, and increased cracking.
- Manganese (Mn)—As the percentage of manganese increases, the tensile strength, hardness, resistance to abrasion, and porosity all increase; hot shortness is reduced. It is also a strong austenite former.
- Silicon (Si)—As the percentage of silicon increases, tensile strength increases and cracking may increase. It is used as a deoxidizer and ferrite former.
- Chromium (Cr)—As the percentage of chromium increases, tensile strength, hardness, and corrosion resistance increase, with some decrease in ductility. It is also a good ferrite and carbide former.
- Nickel (Ni)—As the percentage of nickel increases, tensile strength, toughness, and corrosion resistance increase. It is also an austenite former.
- Molybdenum (Mo)—As the percentage of molybdenum increases, tensile strength increases at elevated temperatures; creep resistance and corrosion resistance all increase, too. It is also a ferrite and carbide former.
- Copper (Cu)—As the percentage of copper increases, the corrosion resistance and cracking tendency increase.
- Columbium (Cb)—As the percentage of columbium (niobium) increases, the tendency to form chrome carbides is reduced in stainless steels. It is also a strong ferrite former.
- Aluminum (Al)—As the percentage of aluminum increases, the high-temperature scaling resistance improves. It is also a good oxidizer and ferrite former.

CARBON EQUIVALENT (CE)

The weldability of an iron alloy is affected by the combination of the alloys used with carbon. To determine the weldability of a specific alloy, formulas have been developed to calculate the carbon equivalence. There are several different formulas, some more complex than others. All of

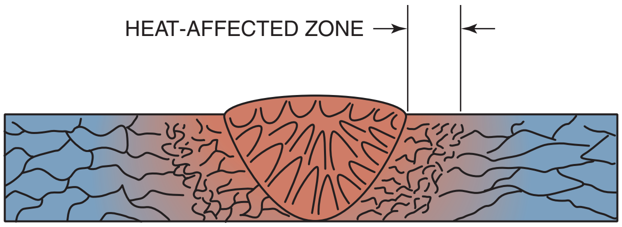


FIGURE 28-1 Heat-affected zone.

the formulas produce the same product, a **carbon equivalent (CE)** value that can be used to determine the weldability of the alloy. The CE value and the percentage of carbon are used similarly. Carbon equivalence or carbon content should be used to determine whether any special procedures are needed to make an acceptable weld. They are used for selecting conditions such as preheat or postheat temperatures and stress releasing. Carbon and its effects on welding are covered in more depth in Chapter 27.

The CE of an alloy is an indication of how the weld will affect the surrounding metal. This area is called the **heat-affected zone (HAZ)**, **Figure 28-1**. The higher the CE, the more effect the weld can have on the surrounding base metal.

By knowing the CE of the metal, the welder can adjust the welding procedure to control problems with the HAZ. Some of the most common adjustments to the welding procedure are preheating and/or postheating, electrode selection, electrode size, electrode type, and current settings.

Using the following CE formula, a welder can make the proper adjustments in the welding procedure for plain carbon steels:

$$CE = \%C + \frac{\%M}{6} + \frac{\%Mo}{4} + \frac{\%C}{5} + \frac{\%Ni}{15} + \frac{\%Cu}{15} + \frac{\%P}{3}$$

- CE = 0.40% or less—no special welding requirements
- CE = 0.40% to 0.60%—low-hydrogen welding electrode and the related procedure required
- CE = 0.60% or more—low-hydrogen welding electrode, higher welding heat inputs, preheating, and controlled cooling rates

SMAW OPERATING INFORMATION

Shielded metal arc welding (SMAW) electrodes, sometimes referred to as welding rods, stick electrodes, or simply electrodes, have two parts. These two parts are the inner core wire and a flux covering, **Figure 28-2**.

The functions of the **core wire** include the following:

- To carry the welding current
- To serve as most of the filler metal in the finished weld

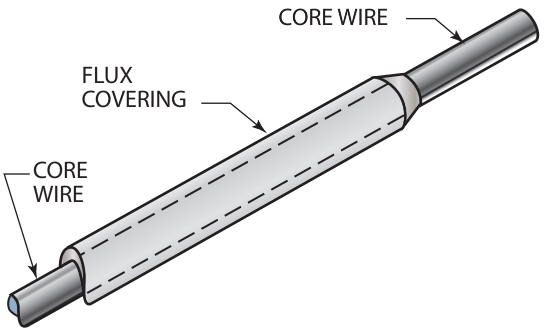


FIGURE 28-2 The two parts of a welding electrode.

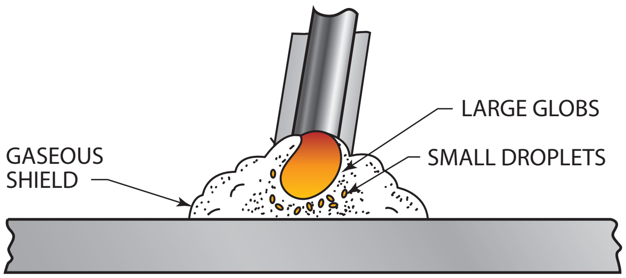


FIGURE 28-3 Methods of metal transfer during an arc.

The functions of the **flux covering** include the following:

- To provide some of the alloying elements
- To provide an arc stabilizer (optional)
- To serve as an insulator
- To provide a slag cover to protect the weld bead and slow cooling rate
- To provide a protective gaseous shield during welding

Core Wire

A core wire is the primary metal source for a weld. For fabricating structural and low-alloy steels, the core wires of the electrode use inexpensive rimmed or low-carbon steel. For more highly alloyed materials, such as stainless steel, high nickel alloys, or nonferrous alloys, the core wires are of the approximate composition of the material to be welded. The core wire also supports the coating that carries the fluxing and alloying materials to the arc and weld pool.

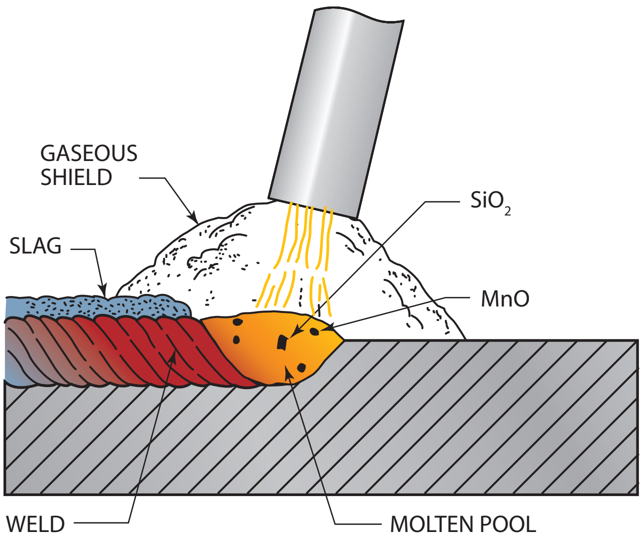


FIGURE 28-4 Silicon and manganese act as scavengers that combine with contaminants and float to the slag on top of the weld.

Functions of the Flux Covering

Provides Shielding Gases Heat generated by the arc causes some constituents in the flux covering to decompose and others to vaporize, forming shielding gases. These gases prevent the atmosphere from contaminating the weld metal as it transfers across the arc gap. They also protect the molten weld pool as it cools to form solid metal. In addition, shielding gases and vapors greatly affect both the drops that form at the electrode tip and their transfer across the arc gap, **Figure 28-3**. They also cause the spatter from the arc and greatly determine arc stiffness and penetration. For example, the E6010 electrode contains cellulose. Cellulose decomposes into the hydrogen responsible for the deep electrode penetration so desirable in pipeline welding.

Alloying Elements Elements in the flux are mixed with the filler metal. Some of these elements stay in the weld metal as alloys. Other elements pick up contaminants in the molten weld pool and float them to the surface. At the surface, these contaminants form part of the slag, **Figure 28-4**.

Effect on Weld Welding fluxes can affect the penetration and contour of the weld bead. Penetration may be pushed deeper if the core wire is made to melt off faster than the flux melts. This forms a small chamber or crucible at the end of the electrode that acts as the combustion chamber of a rocket. As a result, the molten metal and hot gases are forced out very rapidly. The effect of this can be seen on the surface of the molten weld pool as it is blown back away from the end of the electrode. Some electrodes do not use this jetting action, and the resulting molten weld pool is much calmer (less turbulent) and may be rounded in appearance. In addition, the resulting bead may have less penetration, **Figure 28-5**.

Weld bead contour can also be affected by the slag formed by the flux. Some high-temperature slags, called *refractory*, solidify before the weld metal solidifies, forming a mold that holds the molten metal in place. These electrodes are sometimes referred to as **fast freezing** and are excellent for vertical, horizontal, and overhead welding positions.

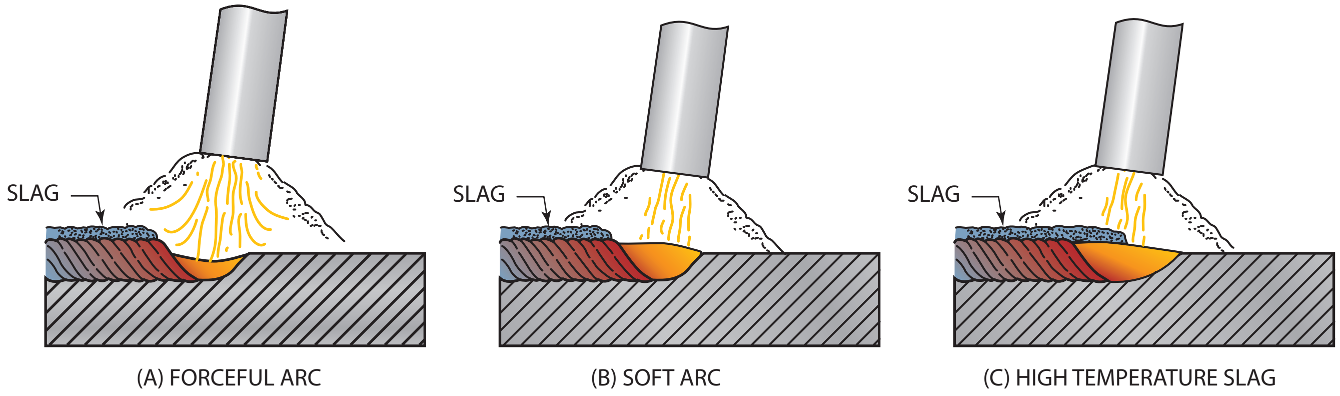


FIGURE 28-5 Arc force. (A) Forceful arc. (B) Soft arc. (C) High-temperature slag.

FILLER METAL SELECTION

Selecting the best filler metal for a job is seldom delegated to the welder in large shops. The selection of the correct process and filler metal is a complex process. If the choice is given to the welder, it is one of the most important decisions the welder will make.

Covering all of the variables for selecting a filler metal would be well beyond the scope of this text. A sample of the types of factors that must be considered for the selection of an SAW electrode follows. To further complicate things, welding electrodes have more than one application, and many welding electrodes may be used for the same type of work.

The following conditions that the welder should consider when choosing a welding electrode are not in order of importance. They are also not all of the factors that must be considered.

Shielded Metal Arc Welding Electrode Selection

- Type of electrode—What electrode has been specified in the blueprints or in the contract for this job?
- Type of current—Can the welding power supply provide AC only, DC only, or both AC and DC?
- Power range—What is the amperage range on the welder and its duty cycle? Different types of electrodes require different amperage settings even for the same size welding electrode. For example, the amperage range for a 1/8-in. (3-mm) diameter E6010 electrode is 75 A to 125 A, and the amperage range for a 1/8-in. (3-mm) diameter E7018 electrode is 90 A to 165 A.
- Type of base metal—Some welding electrodes may be used to join more than one similar type of metal. Other electrodes may be used to join together two different types of metal. For example, an E309-15 electrode can be used to join 305 stainless steel to 1020 mild steel.
- Thickness of metal—The penetration characteristics of each welding electrode may differ. Selecting one electrode that will weld on a specific thickness of material is important. For example, E6013 has very little penetration and is therefore good for welding on sheet metal.
- Weld position—Some welding electrodes can be used to make welds in all positions. Other electrodes may be restricted to making flat, horizontal, and/or vertical position welds; a few electrodes may be used to make flat position welds only.
- Joint design—The type of joint and whether it is grooved or not may affect the performance of the welding electrode. For example, the E7018 electrode does not produce a large, gaseous cloud to protect the molten metal. For this reason, the electrode movement is restricted so that the molten weld pool is not left unprotected by the gaseous cloud.
- Surface condition—It is not always possible to work on new, clean metal. Some welding electrodes will weld on metal that is rusty, oily, painted, dirty, or galvanized.
- Number of passes—The amount of reinforcement needed may require more than one welding pass. Some welding electrodes will build up faster, and others will penetrate deeper. The slag may be removed more easily from some welds than from others. For example, E6013 will build up a weld faster than E6010, and the slag is also more easily removed between weld passes.
- Distortion—Welding electrodes that will operate on low-amperage settings will have less heat input and cause less distortion. Welding electrodes that have a high rate of deposition (fill the joint rapidly) and can travel faster will also cause less distortion. For example, the flux on an E7024 has 50% iron powder, which gives it a faster fill rate and allows it to travel faster, resulting in less distortion of the metal being welded.

- Preheat or postheat—On low-carbon steel plate 1 in. (25 mm) thick or more, preheating is required with most welding electrodes. Postheating may be required to keep a weld zone from hardening or cracking when using some welding electrodes. However, no postheating may be required when welding low-alloy steel using E310-15.
- Temperature service—Weld metals react differently to temperature extremes. Some welds become very brittle and crack easily in cryogenic (low-temperature) service. A few weld metals resist creep and oxidation at high temperatures. For example, E310Mo-15 can weld on most stainless and mild steels without any high-temperature problems.
- Mechanical properties—Mechanical properties such as tensile strength, yield strength, hardness, toughness, ductility, and impact strength can be modified by the selection of specific welding electrodes.
- Postwelding cleanup—The hardness or softness of the weld greatly affects any grinding, drilling, or machining. The ease with which the slag can be removed and the quantity of spatter will affect the time and amount of cleanup required.
- Shop or field weld—The general working conditions such as wind, dirt, cleanliness, dryness, and accessibility of the weld will affect the choice of welding electrode. For example, the E7018 electrode must be kept very dry, but the E6010 electrode is not greatly affected by moisture, **Figure 28-6**.
- Quantity of welds—If a few welds are needed, then a more expensive welding electrode requiring less skill may be selected. For a large production job requiring a higher skill level, a less expensive welding electrode may be best.

After deciding the specific conditions that may affect the welding, the welder has most likely identified more than one condition that needs to be satisfied. Some of the conditions will not interfere with others. For example, the type of current and whether a welder makes one or more weld passes have little or no effect on each other. However, if a welder needs to machine the finished weld, hardness is a consideration. When two or more conditions conflict, the welder is seldom the person who will make the decision. It may be necessary to choose more than one welding electrode. When welding pipe, E6010 and E6011 are often used for the root pass because of their penetration characteristics, and E7018 is used for the cover pass because of its greater strength and resistance to cracking.

Each AWS electrode classification has its own welding characteristics. Some manufacturers have more than one welding electrode in some classifications. In these cases, the minimum specifications for the classification have been exceeded. An example of more than one welding electrode in a single classification is Lincoln's Fleetweld 35, Fleetweld 35LS, and Fleetweld 180R. These electrodes are all in AWS classification E6011. For the manufacturer's complete description of these electrodes, consult **Table 28-1**.


Larry Jeffus

(A)

Phoenix International

(B)

FIGURE 28-6 Most codes and standards require that all electrodes must be stored in a heated electrode storage box to keep them dry (A). Portable thermos-type containers can be carried to the work area by the welder to keep the electrodes dry and ready to use (B).

Electrode Identification and Operating Data

Coating Color	AWS Number on Coating	(L) Lincoln	Electrode	Electrode Polarity	Sizes and Current Ranges (Amps) (Electrodes Are Manufactured in these Sizes for which Curent Ranges Are Given) 3/32″ Size	1/8″ Size	5/32″ Size	3/16″ Size	7/32″ Size	1/4″ Size
Brick red	6010		Fleetweld 5P	DC+	40–75	75–130	90–175	140–225	200–275	220–325[1]
Gray	6011		Fleetweld 35	AC	50–85	75–120	90–160	120–200	150–260	190–300
				DC+	40–75	70–110	80–145	110–180	135–235	170–270
Red brown	6011	Green	Fleetweld 35LS	AC		80–130	120–160			
				DC±		70–120	110–150			
Brown	6011		Fleetweld 180	AC	40–90	60–120	115–150			
				DC±	40–80	56–110	105–135			
Pink	7010-A1		Shield-arc 85	DC+	50–90	75–130	90–175	140–225		
Pink	7010-A1	Green	Shield-arc 85P	DC+				140–225		
Tan	7010-G		Shield-arc Hyp	DC+		75–130	90–185	140–225	160–250	
Gray	8010-G		Shield-arc 70+	DC+		75–130	90–185	140–225		

[1]Range for 5/16″ size is 240–400 amps. DC+ is Electrode Positive. DC– is Electrode Negative.

All tests were performed in conformance with specifications AWS A5.5 and ASME SFA.5.5 in the aged condition for the E7010-G and E8010-G electrodes, and in the stress-relieved condition for Shield-Arc 85 & 85P. Tests for the other products were performed in conformance with specifications AWS A5.1 and ASME SFA.5.1 for the as-welded condition.

Typical Mechanical Properties

Low figures in the stress-relieved tensile and yield strength ranges below for Shield-Arc 85 and 85P are AWS minimum requirements.
Low figures in the as-welded tensile and yield strength ranges below for the other products are AWS minimum requirements.

	Fleetweld 5P	Fleetweld 35	Fleetweld 35LS	Fleetweld 180	Shield-Arc 85	Shield-Arc 85P	Shield-Arc Hyp	Shield-Arc 70+
As-welded tensile strength—psi	62–69,000	62–68,000	62–67,000	62–71,000	70–78,000	70–78,000	70–84,000	80–92,000
Yield point—psi	52–62,000	50–62,000	50–60,000	50–64,000	60–71,000	57–63,000	60–77,000	67–83,000
ductility—% elong. in 2″	22–32	22–30	22–31	22–31	22–26	22–27	22–23	19–24
Charpy V-notch toughness —ft.-lb	20–60 @–20°F	20–90 @–20°F	20–57 @–20°F	20–54 @–20°F	68 @ 70°F	68 @ 70°F	30 @ 20°F	40 @ 50°F
Hardness, Rockwell B (avg)[5]	76–82	76–85	73–88	75–85			83–92	88–93
Stress-relieved @ 1150°F tensile strength—psi	60–69,000	60–66,000	60–65,000		70–83,000	70–74,000	80–82,000	80–84,000
Yield point—psi	46-56,000	46-56,000	46-51,000		57–69,000	57–65,000	72–76,000	71–76,000
ductility—% elong. in 2″	28–36	28–36	28–33		22–28	22–27	24–27	22–26
Charpy V-notch toughness —ft.-lb	71 @ 70°F		120 @ 70°F		64 @ 70°F	68 @ 70°F	30 @ –20°F	30 @ –50°F
Hardness, Rockwell B (avg)[2]					80–89	80–87		

[2]Hardness values obtained from welds made in accordance with AWS A5.5.

Conformances and Approvals

See Lincoln Price Book for certificate numbers, size, and position limitations, and other data.

Conforms to test requirements of AWS—A5.1 and ASME—SFA5.1 AWS—A5.5 and ASME—SFA5.5	*FW-5P* E6010	*FW-35* E6011	*FW-35LS* E6011	*FW-180* E6011	*SA-85* E7010-A1[3]	*SA-85P* E7010-A1	*SA-HYP* E7010-G	*SA-70+* E8010-G
ASME boiler code Group	F3	F3	F3	F3	F3	F3	F3	F3
Analysis	A1		A1	A1	A2	A2	A2	
American Bureau of Shipping and U.S. Coast Guard	Approved	Approved	Approved		Approved			
Conformance certificate available[3]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Lloyds	Approved	Approved						
Military specifications	MIL-QQE-450	MIL-QQE-450			MIL-E-22200/7			

[3]Certificate of Conformance" to AWS classification test requirements is available. These are needed for Federal Highway Administration projects.

The Lincoln Electric Company

TABLE 28-1 Fleetweld 35®, Fleetweld 35LS®, and Fleetweld 180® Lincoln Electrodes

The characteristics of each manufacturer's filler metals can be compared to one another by using data sheets supplied by the manufacturer. General comparisons can be made easily using an electrode comparison chart.

When making an electrode selection, many variables must be kept in mind, and the performance characteristics must be compared before making a final choice.

AWS FILLER METAL CLASSIFICATIONS

The AWS classification system uses a series of letters and numbers in a code that gives the important information about the filler metal. The prefix letter is used to indicate the filler's form, a type of process the filler is to be used with, or both. The prefix letters and their meanings are as follows:

- **E**—Indicates an arc welding **electrode (E)**. The filler carries the welding current in the process. We most often think of the *E* standing for an SMA "stick" welding electrode. It also is used to indicate wire electrodes used in GMAW, FCAW, SAW, ESW, EGW, etc.
- **R**—Indicates a **rod (R)** that is heated by some source other than electric current flowing directly through it. Welding rods are sometimes referred to as being "cut length" or "welding wire." It is often used with OFW and GTAW.
- **ER**—Indicates a filler metal that is supplied for use in either an **electrode or rod (ER)** form. The same alloys are used to produce the electrodes and the rods. This filler metal may be supplied as a wire on a spool for GMAW or as a rod for OFW or GTAW.
- **EC**—Indicates a **composite electrode (EC)**. These electrodes are used for SAW. Do not confuse an ECu, copper arc welding electrode, for an ECNi2, which is a composite nickel submerged arc welding wire.
- **B**—Indicates a **brazing (B)** filler metal. This filler metal is usually supplied as a rod, but it can come in a number of other forms. Some of the forms it comes in are powder, sheets, washers, and rings.
- **RB**—Indicates a filler metal that is used as a current carrying electrode, as a rod, or both (**electrode and/or rod [RB]**). The form the filler is supplied in for each of the applications may be different. The composition of the alloy in the filler metal will be the same for all of the forms supplied. This filler can be used for processes like arc braze welding or oxyfuel brazing.
- **RG**—Indicates a welding rod used primarily with gas welding (**oxyfuel welding**) . This filler can be used with all of the oxyfuels, and some of the fillers are used with the GTAW process.
- **IN**—Indicates a consumable **insert (IN)**. These are most often used for welding on pipe. They are pre-placed in the root of the groove to supply both filler metal and support for the root pass. The inserts may provide for some joint alignment and spacing.

The next two classifications are not filler metal. They are classified under the same system because they are welding consumables. The GTA welding tungsten is not a filler, but it is consumed, very slowly, during the welding process.

- **EW**—Indicates a nonconsumable **tungsten electrode (EW)**. The GTAW electrode is obviously not a filler metal, but it falls under the same classification system.
- **F**—Indicates a **flux (F)** used for SAW. The composition of the weld metal is influenced by the flux. There are alloys and agents in the flux used for SAW that are dissolved into the weld metal. For this reason, the filler metal and flux are specified together, with the filler metal identification first and the flux second.

In addition to the prefix, there are some suffix identifiers. The suffix may be used to indicate a change in the alloy in a covered electrode or the type of welding current to be used with stainless steel–covered electrodes.

CARBON STEEL

Carbon and Low-Alloy Steel–Covered Electrodes

The AWS specification for carbon steel–covered arc electrodes is A5.1, and for low-alloy steel–covered arc electrodes it is A5.5. Filler metals classified within these specifications are identified by a system that uses the letter *E* followed by a series of numbers to indicate the minimum tensile strength of a good weld, the position(s) in which the electrode can be used, the type of flux coating, and the type(s) of welding current, **Figure 28-7**.

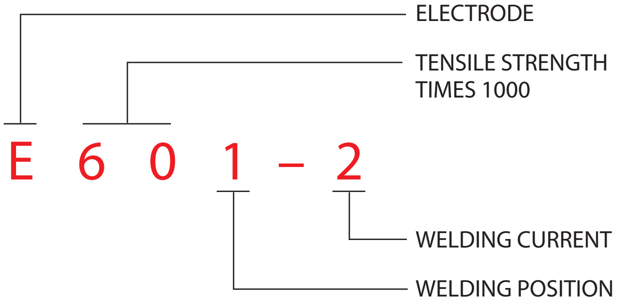


FIGURE 28-7 AWS numbering system for A5.1 and A5.5 carbon and low-alloy steel-covered electrodes.

The tensile strength is given in pounds per square inch (psi). The actual strength is obtained by adding three zeroes to the right of the number given. For example, E60XX is 60,000 psi, E110XX is 110,000 psi, and so on.

The next number located to the right of the tensile strength—1, 2, or 4—designates the welding position capable—for example:

- 1—in an E601X means all positions flat, horizontal, vertical, and overhead.
- 2—in an E602X means horizontal fillets and flat.
- 3—is an old term no longer used; it meant flat only.
- 4—in an E704X means flat, horizontal, overhead, and vertical down.

The last two numbers together indicate the major type of covering and the type of welding current. For example, EXX10 has an organic covering and uses DCEP polarity. The AWS classification system for A5.1 and A5.5 covered arc welding electrodes is shown in **Table 28-2**. The type of welding current for any electrode may be expanded to include currents not listed if a manufacturer adds additional arc stabilizers to the electrode covering, **Table 28-3**.

EXXX0—DCRP only
EXXX1—AC and DCRP
EXXX2—AC and DCSP
EXXX3—AC and DC
EXXX4—AC and DC
EXXX5—DCRP only
EXXX6—AC and DCRP
EXXX8—AC and DCRP

TABLE 28-3 Welding Currents

On some covered arc electrodes, a suffix may be added to indicate the approximate alloy in the deposit as welded. For example, the letter *A* indicates a 1/2% molybdenum addition to the weld metal deposited. **Table 28-4** is a complete list of the major **alloying elements** in electrodes.

Some of the more popular arc welding electrodes and their uses in these specifications are as follows:

E6010 The E6010 electrodes are designed to be used with DCEP polarity and have an organic-based flux (cellulose, $C_6H_{10}O_5$). They have a forceful arc that results in deep penetration and good metal transfer in the vertical and overhead positions, **Figure 28-8**. The electrode is

AWS Classification	Type of Covering	Capable of Producing Satisfactory Welds in Positions Shown[a]	Type of Current[b]
	E60 Series Electrodes		
E6010	High cellulose sodium	F, V, OH, H	DC, reverse polarity
E6011	High cellulose potassium	F, V, OH, H	AC or DC, reverse polarity
E6012	High titania sodium	F, V, OH, H	AC or DC, straight polarity
E6013	High titania potassium	F, V, OH, H	AC or DC, either polarity
E6020		H-fillets	AC or DC, straight polarity
E6022[c]	High iron oxide	F	AC or DC, either polarity
E6027	High iron oxide, iron powder	H-fillets, F	AC or DC, straight polarity
	E70 Series Electrodes		
E7014	Iron powder, titania	F, V, OH, H	AC or DC, either polarity
E7015	Low hydrogen sodium	F, V, OH, H	DC, reverse polarity
E7016	Low hydrogen potassium	F, V, OH, H	AC or DC, reverse polarity
E7018	Low hydrogen potassium, iron powder	F, V, OH, H	AC or DC, reverse polarity
E7024	Iron powder, titania	H-fillets, F	AC or DC, either polarity
E7027	High iron oxide, iron powder	H-fillets, F	AC or DC, straight polarity
E7028	Low hydrogen potassium, iron powder	H-fillets, F	AC or DC, reverse polarity
E7048	Low hydrogen potassium, iron powder	F, OH, H, V-down	AC or DC, reverse polarity

[a]The abbreviations F, V, V-down, OH, H, and H-fillets indicate the welding positions as follows:

F = Flat
H = Horizontal
H-fillets = Horizontal fillets
V-down = Vertical down
V = Vertical
OH = Overhead

[b]Reverse polarity means the electrode is positive; straight polarity means the electrode is negative.

[c]Electrodes of the E6022 classification are for single-pass welds.

For electrodes 3/16 in. (4.8 mm) and under, except 5/32 in. (4.0 mm) and under for classifications E7014, E7015, E7016, and E7018.

American Welding Society

TABLE 28-2 Electrode Classification

Suffix Symbol	Molybdenum (Mo) %	Nickel (Ni) %	Chromium (Cr) %	Manganese (Mn)%	Vanadium (Va) %
A 1	0.5				
B 1	0.5		0.50		
B 2	0.5		1.25		
B 3	1.0		2.25		
B 4	0.5		2.00		
C 1		2.5			
C 2		3.5			
C 3		1.0			
D 1	0.3			1.5	
D 2	0.3			1.75	
G	0.2	0.5	0.30	1.00	0.1*
M					

*Only one of these alloys may be used.

TABLE 28-4 Major Alloying Elements in Electrodes

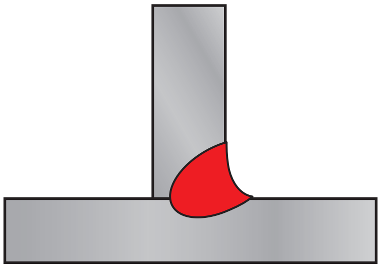


FIGURE 28-8 E6010.

usually used with a whipping or stepping motion. This motion helps remove unwanted surface materials such as paint, oil, dirt, and galvanizing. Both the burning of the organic compound in the flux to form CO_2, which protects the molten metal, and the rapid expansion of the hot gases force the atmosphere away from the weld. A small amount of slag remains on the finished weld, but it is difficult to remove, especially along the weld edges. E6010 electrodes are commonly used for welding on fired and unfired pressure vessels, on pipe, and in construction jobs, shipyards, and repair work.

E6011 The E6011 electrodes are designed to be used with AC or DCEP reverse polarity and have an organic-based flux. These electrodes have many of the welding characteristics of E6010 electrodes, **Figure 28-9**. In most applications, the E6011 is preferred. The E6011 has added arc stabilizers, which allow it to be used with AC. Using this welding electrode on AC only slightly reduces its penetration but will help control any arc blow problem. **Arc blow**, or arc wander, occurs when using DC current and is the magnetic deflection of the arc from its normal path. Arc blow does not occur when alternating current is used. When welding with either E6010 or E6011, the weld pool may be slightly concave from the forceful action of the rapidly expanding gas. This forceful action also results in more spatter and sparks during welding.

E6012 The E6012 electrodes are designed to be used with AC or DCEN polarity and to have rutile-based flux (titanium dioxide TiO_2). This electrode has a very stable arc that is not very forceful, resulting in a shallow penetration characteristic, **Figure 28-10**. This limited penetration characteristic helps with poor-fitting joints or thin materials. Thick sections can be welded, but the joint must be grooved. Less smoke is generated with this welding electrode than with E6010 or E6011, but a thicker slag layer is deposited on the weld. If the weld is properly made, the slag can be removed easily and may even free itself after cooling. Spatter can be held to a minimum when using both AC and DC. E6012 electrodes are commonly used for all new work, including storage tanks, machinery fabrication, ornamental iron, and general repair work.

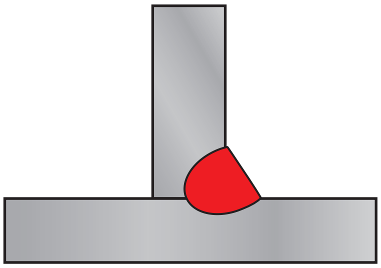


FIGURE 28-9 E6011.

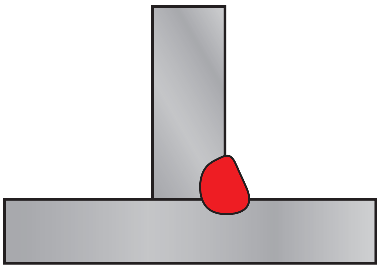


FIGURE 28-10 E6012.

E6013 The E6013 electrodes are designed to be used with AC or DC, either polarity. They have a rutile-based flux. The E6013 electrode has many of the same characteristics of the E6012 electrode, **Figure 28-11**. The slag layer is usually thicker on the E6013 and is easily removed. The arc of the E6013 is as stable, but there is less penetration, which makes it easier to weld very thin sections. The weld bead will also be built up slightly higher than the E6012. E6013 electrodes are commonly used for sheet metal fabrication, metal buildings, surface buildup, truck and automotive bodywork, and farm equipment.

E7014 The E7014 electrodes are designed to be used with AC or DC, either polarity. They have a rutile-based flux with iron powder added. The E7014 electrode has many arc and weld characteristics that are similar to those of the E6013 electrode, **Figure 28-12**. Approximately 30% iron powder is added to the flux to allow it to build up a weld faster or have a higher travel speed. The penetration characteristic is light. This welding electrode can be used on metal with a light coating of rust, dirt, oil, or paint. The slag layer is thick and hard but can be completely removed with chipping. E7014 electrodes are commonly used for welding on heavy sheet metal, ornamental iron, machinery, frames, and general repair work.

E7024 The E7024 electrodes are designed to be used with AC or DC, either polarity. They have a rutile-based flux with iron powder added. This welding electrode has a light penetration and fast fill characteristic, **Figure 28-13**. The flux contains approximately 50% iron powder, which gives the flux its high rate of deposition. The heavy flux coating helps control the arc and can support the electrode so that a drag technique can be used. The drag technique allows this electrode to be used by welders with less skill. The slag layer is heavy and hard but can easily be removed. If the weld is performed correctly, then the slag may remove itself. Because of the large, fluid molten weld pool, this electrode is equally used in the flat and horizontal position only, although it can be used on work that is slightly vertical. E7024 electrodes are commonly used for welding earth-moving, mining, and railroad equipment.

E7016 The E7016 electrodes are designed to be used with AC or DCEP polarity. They have a low-hydrogen–based (mineral) flux. This electrode has moderate penetration and little buildup, **Figure 28-14**. There is no iron powder in the flux, which helps when welding in the vertical or overhead positions. Welds on high-sulfur and cold-rolled metals can be made with little porosity. Low-alloy and mild steel heavy plates can be welded with minimum preheating. E7016 electrodes are commonly used for construction, earth-moving and mining equipment, and shipbuilding.

E7018 The E7018 electrodes are designed to be used with AC or DCEP polarity. They have a low-hydrogen–based flux with iron powder added. The E7018 electrodes have moderate penetration and buildup, **Figure 28-15.** The slag

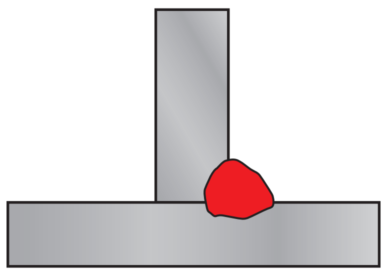


FIGURE 28-13 E7024.

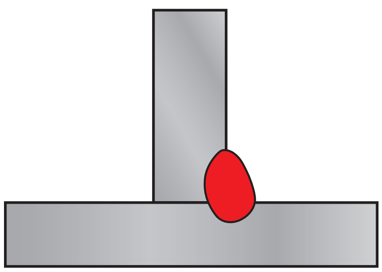


FIGURE 28-11 E6013.

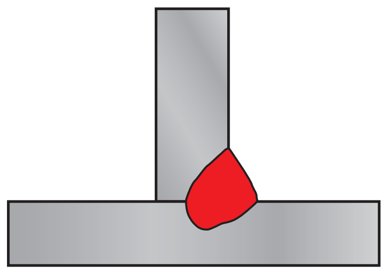


FIGURE 28-14 E7016.

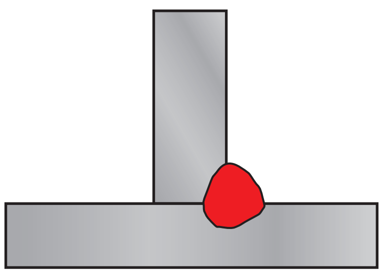


FIGURE 28-12 E7014.

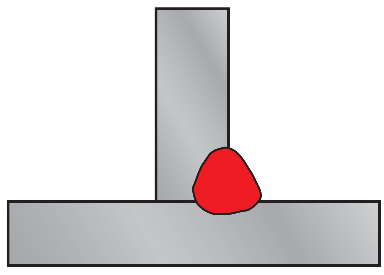


FIGURE 28-15 E7018.

layer is heavy and hard but can be removed easily by chipping. The weld metal is protected from the atmosphere primarily by the molten slag layer and not by rapidly expanding gases. For this reason, these electrodes should not be used for open root welds. The atmosphere may attack the root, causing a porosity problem. The E7018 welding electrodes are very susceptible to moisture, which may lead to weld porosity. These electrodes are commonly used for pipe, heavy sections of plate, shipbuilding, boiler work, and low-temperature equipment. E7018 electrodes are sometimes referred to as Lo-Hi rods because they allow very little hydrogen into the weld pool.

WIRE-TYPE STEEL FILLER METALS

Solid Wire

The AWS specification for carbon steel filler metals for gas shielded welding wire is A5.18. Filler metal classified within these specifications can be used for GMAW, GTAW, and PAW processes. Because in GTAW and PAW the wire does not carry the welding current, the letters *ER* are used as a prefix. The *ER* is followed by two numbers to indicate the minimum tensile strength of a good weld. The actual strength is obtained by adding three zeroes to the right of the number given. For example, ER70S-x is 70,000 psi.

The *S* located to the right of the tensile strength indicates that this is a solid wire. The last number—2, 3, 4, 5, 6, or 7—or the letter *G* is used to indicate the filler metal composition and the weld's mechanical properties, **Figure 28-16.**

ER70S-2 This is a deoxidized mild steel filler wire. The deoxidizers allow this wire to be used on metal that has light coverings of rust or oxides. There may be a slight reduction in the weld's physical properties if the weld is made on rust or oxides, but this reduction is only slight, and the weld will usually still pass the classification test standards. This is a general-purpose filler that can be used on killed, semi-killed, and rimmed steels. Argon-oxygen, argon-CO_2, and CO_2 can be used as shielding gases. Welds can be made in all positions.

ER70S-3 This is a popular filler wire. It can be used in single or multiple pass welds in all positions. ER70S-3 does not have the deoxidizers required to weld over rust, over oxides, or on rimmed steels. It produces high-quality welds on killed and semi-killed steels. Argon-oxygen, argon-CO_2, and CO_2 can be used as shielding gases.

ER70S-6 This is a good general-purpose filler wire. It has the highest levels of manganese and silicon. The wire can be used to make smooth welds on sheet metal or thicker sections. Welds over rust, oxides, and other surface impurities will lower the mechanical properties, but not normally below the specifications of this classification. Argon-oxygen, argon-CO_2, and CO_2 can be used as shielding gases. Welds can be made in all positions.

Tubular Wire

The AWS specification for carbon steel filler metals for flux cored arc welding wire is A5.36/A5.36M. The A5.36 specification uses customary U.S. units and the A5.36M uses the SI measuring units. Flux cored filler metals classified within this specification can be used for the FCAW process. The letter *E*, for *electrode*, is followed by a single number to indicate the minimum tensile strength of a good weld. The actual strength is obtained by adding four zeroes to the right of the number given. For example, E6xT-x is 60,000 psi, and E7xT-x is 70,000 psi.

The next number, 0 or 1, indicates the welding position. Ex0T is to be used in a horizontal or flat position only. Ex1T is an all-position filler metal.

The *T* located to the right of the tensile strength and weld position numbers indicates that this is a tubular, flux cored wire. The last number—2, 3, 4, 5, 6, 7, 8, 10, or 11—or the letter *G* or *GS* is used to indicate if the filler metal can be used for single or multiple pass welds. The electrodes with the numbers ExxT-2, ExxT-3, ExxT-10, and ExxT-GS are intended for single pass welds only, **Figure 28-17**.

Heated storage lockers are available to keep all wire electrodes dry to prevent surface oxidation and keep moisture out of the flux core of FCAW electrodes, **Figure 28-18**.

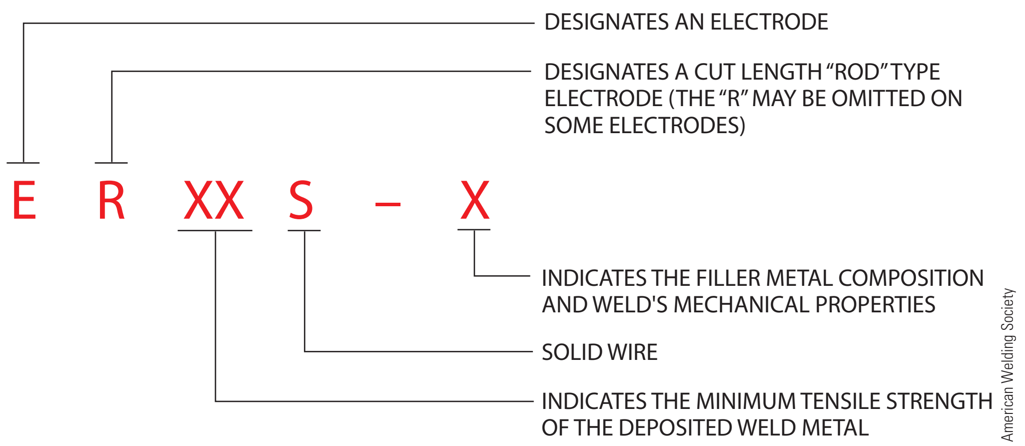


FIGURE 28-16 AWS numbering system for carbon steel filler metal for GMAW.

Mandatory Classification Designators[1] for FCAW Carbon Steel Electrodes

Designates an electrode.

Tensile strength designator. For A5.20 this designator indicates the minimum tensile strength (when multiplied by 10,000 psi) of the weld metal when the weld is made in the manner prescribed by this specification. For A5.20M two digits are used to indicate the minimum tensile strength (when multiplied by 10 MPa).

Position designator. This designator is either "0" or "1". "0" is for flat and horizontal positions only. "1" is for all positions (flat, horizontal, vertical with downward progression and/or vertical with upward progression and overhead).

This designator identifies the electrode as a flux cored electrode.

Usability designator. This designator is some number from 1 through 14 or the letter "G" (or "GS"). This designator refers to the usability of the electrode with requirements for polarity and general operating characteristics (see Table 2 in A5.20). The letter "G" indicates that the polarity and general operating characteristics are not specified. An "S" is used after the "G" to indicate that the electrode is suitable only for single pass welding.

Shielding gas designator.[2] Indicates the type of shielding gas used for classification. The letter "C" indicates that the electrode is classified using 100% CO2 shielding gas. The letter "M" indicates that the electrode is classified using 75–80% Argon/balance CO2 shielding gas. When no designator appears in this position, it indicates that the electrode being classified is self-shielded and that no external shielding gas was used.

E X X T - X X - J X HX

Optional Supplemental Designators[3]

Optional supplemental diffusible hydrogen designator (see Table 8 in A5.20).

The letter "D" or "Q" when present in this position indicates that the weld metal will meet supplemental mechanical property requirements with welding done using low heat input, fast cooling rate procedures and using high heat input, slow cooling rate procedures as prescribed in Section 17 (see Tables 9 and 10 in A5.20).

The letter "J" when present in this position designates that the electrode meets the requirements for improved toughness and will deposit weld metal with Charpy V-Notch properties of at least 20 ft-lbf at −40°F [27J at −40°C] when the welds are made in a manner prescribed by these specifications.

Notes:
1. The combination of these designators constitutes the flux cored electrode classification.
2. See AWS A5.32/A5.32M.
3. These designators are optional and do not constitute a part of the flux cored electrode classification.

Source: AWS A5.20/A5.20M: 2005, *Specification for Carbon Steel Electrodes for Flux Cored Arc Welding*.

American Welding Society

FIGURE 28-17 Identification system for mild steel FCAW electrodes.

Phoenix International

FIGURE 28-18 Heated storage lockers are available for all types of wire electrodes.

E70T-1 and E71T-1 E70T-1 and E71T-1 have a high-level deoxidizer in the flux core. It has high levels of silicon and manganese, which allow it to weld over some surface contaminations such as oxides or rust. This filler metal can be used for single or multiple pass welds. Argon 75% with 25% CO_2 or 100% CO_2 can be used as the shielding gas. It can be used on ASME A36, A106, A242, A252, A285, A441, and A572 or similar metals. Applications include railcars, heavy equipment, earth-moving equipment, shipbuilding, and general fabrication. The weld metal deposited has a chemical and physical composition similar to that of E7018 low-hydrogen electrodes.

E70T-2 and E71T-2 E70T-2 and E71T-2 are highly deoxidized flux cored filler metal that can be used for single pass welds only. The high levels of deoxidizers allow this electrode to be used over mill scale and light layers of rust and still produce sound welds. Because of the high level of manganese, if the filler is used for multiple pass welds, then there might be manganese-caused centerline cracking of the weld; 100% CO_2 can be used as the shielding gas. E70T-2 can be used on ASME A36, A106, A242, A252, A285, A441, and A572 or similar metals. Applications include repair and maintenance work and general fabrication.

E70T-4 and E71T-4 E70T-4 and E71T-4 are self-shielding, flux cored filler metal. The fluxing agents produce a

slag, which allows a larger-than-usual molten weld pool. The large weld pool permits high deposition rates. Weld deposits are ductile and have a high resistance to cracking. E70T-4 can be used to weld joints that have larger-than-usual root openings. Applications include large weldments and earth-moving equipment.

E71T-7 E71T-7 is a self-shielding, all-position, flux cored filler metal. The fluxing system allows the control of the molten weld pool required for out-of-position welds. The high level of deoxidizers reduces the tendency for cracking in the weld. It can be used for single or multiple pass welds.

Metal Cored Arc Welding Electrodes

The AWS specification for metal cored electrodes is *A5.36/A5.36M Specification for Carbon and Low-Alloy Steel Flux Cored Electrodes for Flux Cored Arc Welding and Metal Cored Electrodes for Gas Metal Arc Welding*. Metal cored electrodes are similar to FCA welding electrodes in that they are tubular in design and are filled with a mixture. FCA welding electrodes contain between 5% and 15% nonmetallic compounds that act as fluxes or shielding gas formers. However, metal cored electrodes contain 2% or less nonmetallic compounds in the core material.

Metal cored electrodes classified as E70C-XX may be used for single and multiple pass welds. It is considered a high-performance filler metal because it can be used in high production applications. It has a 98% or higher deposition rate due to its low nonmetallic and high metallic power. It has enough deoxidizers to allow it to be used over light rust and mill scale without weld porosity. These metal cored filler metals are used where high-strength welds are needed in structural steel, farm equipment, high-performance vehicles such as race cars, off-road 4 × 4 vehicles, and drag racers. In addition to manual welding, E70C-XX filler metals are frequently used in automatic and robotic welding applications.

Stainless Steel Electrodes

The AWS specification for stainless steel–covered arc electrodes is A5.4, and for stainless steel bare, cored, and stranded electrodes and welding rods is A5.9. Filler metal classified within the A5.4 uses the letter *E* as its prefix, and the filler metal within the A5.9 uses the letters *ER* as its prefix, **Table 28-5**.

Following the prefix, the American Iron and Steel Institute's (AISI) three-digit stainless steel number is used. This number indicates the type of stainless steel in the filler metal.

To the right of the AISI number, the AWS adds a dash followed by a suffix number. The number 15 is used to indicate that there is a lime base coating, and the DCEP polarity welding current should be used. The number 16 is used to indicate there is a titania-type coating, and AC or DCEP polarity welding currents can be used. Examples of this classification system are E308-15 and E308-16 electrodes.

The letter *L* may be added to the right of the AISI number before the dash and suffix number to indicate a low-carbon stainless welding electrode. E308L-15 and E308L-16 arc welding electrodes and ER308L and ER316L are examples of the use of the letter *L*, **Table 28-6**.

Stainless steel may be stabilized by adding columbium (Cb) as a carbide former. The designation Cb is added after the AISI number for these electrodes, such as E309Cb-16. Stainless steel filler metals are stabilized to prevent chromium-carbide precipitation.

E308-15, E308-16, E308L-15, ER308, and ER308L All are filler metals for 308 stainless steels. These 308 stainless steels are used for food or chemical equipment, tanks, pumps, hoods, and evaporators. All E308 and ER308 filler metals can be used to weld on all 18-8–type stainless steels such as 301, 302, 302B, 303, 304, 305, 308, 201, and 202.

E309-15, E309-16, E309Cb-15, E309Cb-16, ER309, and ER309L All are filler metals for 309 stainless steels. These 309 stainless steels are used for high-temperatures service, such as furnace parts and mufflers. All E309 filler metals can be used to weld on 309 stainless or to join mild steel to any 18-8–type stainless steel.

E310-15, E310-16, E309Cb-15, E309Cb-16, E310Mo-15, E310Mo-16, and ER310 All are filler metals for 310 stainless steels. These 310 stainless steels are used for high-temperature service where low creep is desired, such as for jet engine parts, valves, and furnace parts. All E310 filler metals can be used to weld 309 stainless steel or to join mild steel to stainless steel or to weld most hard-to-weld carbon and alloy steels. E310Mo-15 and 16 electrodes have molybdenum added to improve their strength at high temperatures and to resist corrosive pitting.

E316-15, E316-16, E3116L-15, E316L-16, ER316, ER316L, and ER316L-Si All are filler metals for 316 stainless steels. These 316 stainless steels are used for high-temperature service where high strength with low creep is desired. Molybdenum is added to improve these properties and to resist corrosive pitting. E316 filler metals are used for welding tubing, chemical pumps, filters, tanks, and furnace parts. All E316 filler metals can be used on 316 stainless steels or when weld resistance to pitting is required.

Nonferrous Electrodes

The AWS identification system for covered nonferrous electrodes is based on the atomic symbol or symbols of the major alloy(s) or the metal's identification number. The alloy with the largest percentage appears first in the identification. The atomic symbol is prefixed by the letter *E*. For example, ECu is a covered copper arc welding electrode, and ECuNiAl is a copper-nickel-aluminum alloy–covered arc welding electrode. A letter, number, or letter–number combination may be added to the right of the atomic symbol to indicate some special alloys. For example, ECuAl-A2 is a copper-aluminum welding electrode that has 1.59% iron added.

AISI TYPE NUMBER	442 446	430F 430FSE	430 431	501 502	416 416SE	403 405 410 420 414	321 348 347	317	316L	316	314	310 310S	309 309S	304L	303 303SE	201 202 301 302 302B 304 305 308	Mild Steel
201-202-301 302-3028-304 305-308	**310** 312 309	**310** 312 309	**310** 312 309	**310** 312 309	**309** 310 312	**309** 310 312	**308**	**308**	**308**	**308**	**308**	**308**	**308**	**308**	**308**	**308**	**312** 310 309
303 303SE	**310** 309 312	**310** 309 312	**310** 309 312	**310** 309 312	**309** 310 312	**309** 310 312	**308**	**308**	**308**	**308**	**308**	**308**	**308**	**308**	**308-15**	**308**	**312** 310 309
304L	**310** 309 312	**310** 309 312	**310** 309 312	**310** 309 312	**309** 310 312	**309** 310 312	**308**	**308**	**308L**	**308**	**308**	**308**	**308**	**308-L**	**308**	**308**	**312** 310 309
309 309S	**310** 309 312	**310** 309 312	**310** 309 312	**310** 309 312	**309** 310 312	**309** 310 312	**308**	**317** 316 309	**316**	**316**	**309**	**309**	**309**	**308**	**308**	**308**	**309** 310 312
310 310S	**310** 309 312	**310** 309 312	**310** 309 312	**310** 309 312	**310** 309 312	**310** 309 312	**308**	**317** 316 309	**316**	**316**	**310**	**310**	**309** 310	**308**	**308**	**308**	**310** 309 312
314	**310** 312 309	**310** 312 309	**310** 312 309	**310** 312 309	**310** 312 309	**310** 309 312	**309** 310 308	**309** 310	**309** 310	**309** 310	**310-15**	**310**	**309** 310	**309** 310	**309** 310	**309** 310	**310** 309 312
316	**310** 309 312	**310** 309 312	**310** 309 312	**310** 309 312	**309** 310 312	**309** 310 312	**308**	**316**	**316**	**316**	**309** 310 316	**310** 309 316	**309** 310 316	**308** 316	**308** 316	**308** 316	**309** 310 312
316L	**310** 309 312	**310** 309 312	**310** 309 312	**310** 309 312	**309** 310 312	**309** 310 312	**308**	**316** 317 308	**316-L**	**316**	**309** 310 316	**310** 309 316	**316** 309	**308** 316	**308** 316	**308** 316	**309** 310 312
317	**310** 309 312	**310** 309 312	**310** 309 312	**310** 309 312	**309** 310 312	**309** 310 312	**308**	**317**	**316** 308	**316** 308	**309** 310 317	**317** 316 309	**317** 316 309	**308** 316 317	**308** 316 317	**308** 316 317	**309** 310 312
321 348 347	**310** 309 312	**310** 309 312	**310** 309 312	**310** 309 312	**309** 310 312	**309** 310 312	347	**308** 347	**347** 308	**347** 308	**309** 310 347	**347** 308	**347** 308	**347** 308-L	**347** 308	**347** 308	**309** 310 312
403-405 410-420 414	**310** 309 312	**310** 309 312	**310** 309 312	**310** 309 312	**309** 310	**410*** 309**	**309** 310	**309** 310	**309** 310	**309** 310	**310** 309	**310** 309	**309** 310	**309** 310	**309** 310	**309** 310	**309** 310 312
416 416SE	**310** 309	**310** 309	**310** 309	**310**	**410-15***	**410-15*** 309** 310**	**309** 310	**309** 310 312	**309** 310 312	**309** 310 312	**309** 310 312	**310** 309 312	**309** 310 312	**309** 310 312	**309** 310 312	**309** 310 312	**309** 310 312
501 502	**310**	**310**	**310**	**502*** 310**	**310**	**310**	**310** 309	**310** 309	**310** 309	**310** 309	**310** 309	**310** 309	**310** 309	**310** 309	**310** 309	**310** 309	**310** 312 309
430 431	**310** 309	**310** 309	**430-15*** 310** 309**	**310**	**310**	**310** 309	**310** 309	**310** 309	**310** 309	**310** 309	**310** 309	**310** 309	**310** 309	**310** 309	**310** 309	**310** 309	**310** 309 312
430F 430FSE	**310** 309	**410-15***	**310** 309	**310** 309	**310** 309 312	**310** 309 312	**309** 310 312	**309** 310 312	**310** 309 312	**310** 309 312	**310** 309 312	**310** 309 312	**310** 309 312	**310** 309 312	**310** 309 312	**310** 309 312	**310** 309 312
442 443	**309** 310	**309** 310 312	**310** 309 312	**310** 309 312	**310** 309 312	**310** 309 312	**310** 309 312	**310** 309 312	**310** 309 312	**310** 309 312	**310** 309 312	**310** 309 312	**310** 309 312	**310** 309 312	**310** 309 312	**310** 309 312	**310** 309 312

*Preheat.

**No preheat necessary.

Bold numbers indicate first choice; light numbers indicate second and third choices. This choice can vary with specific applications and individual job requirements.

Thermacote Welco

TABLE 28-5 Major Alloying Elements in Electrodes

UTP Designation	AWS/SFA5.4 Covered	AWS/SFA5.9 TIG and MIG	Description and Applications
6820	E308-16	ER308	For welding conventional 308 type SS
68 Kb	E308-15		Low hydrogen coating
6820 Lc	E308 L-16	ER308L	Low carbon grade, prevents carbide precipitation adjacent to weld
308L Fe Hp	E308 L-16		Fast depositing for maintenance and production coating
68 LcHL	E308 L-16		High-performance electrode with rutile-acid coating, core wire alloyed, for stainless and acid-resisting CrNi steels
68 LcKb	E308 L-15		Low carbon electrode for stainless, acid-resisting CrNi-steels
6824	E309-16	ER309	For welding 309 type SS and carbon steel to SS
6824 Kb	E309-15		Special lime-coated electrode for corrosion and heat-resistant 22/12 CrNi-steels
6824 Lc	E309 L-16	ER309L	Same as 309, but with low carbon content
6824 Nb	E309 Cb-16		Corrosion and heat-resistant 22/12 CrNi-steels
6824 MoNb	E309MoCb-16		Corrosion and heat-resistant 22/12 CrNi-steels
309L Fe Hp	E309 L-16		High deposition rate, easy to use
6824 Mo Lc	E309 L-16		For welding similar and dissimilar SS
68H	E310-16	ER310	For high-temperature service and cladding steel
6820 Mo	E316-16	ER316	For welding acid-resistant stainless steels
6820 Mo Lc	E316 L-16	ER316L	Low carbon grade, prevents intergranular corrosion
68 TI Mo	E316 L-16		Most efficient type, for maintenance and production, high performance
68 MoLcHL	E316 L-16		High-performance electrode with rutile-acid coating, core wire alloyed, for stainless and acid-resisting CrNi-Mo-steels
68 MoLcKb	E316 L-15		Low carbon electrode for stainless and acid-resisting CrNiMo-steels
317 Lc Titan	E317 L-16	ER317L	Deposit resist sulfuric acid corrosion
317LFe Hp	E 317 L16		Fast melt-off rate, excellent for overlays, easy to use, high performance
68 Mo	E318-16		Versatile stainless all-position electrode
320 Cb	E320-15		For welding similar acid-resistant SS
3320 Lc	E320		A rutile-coated electrode for welding in all positions except vertical down
6820 Nb	E347-16	ER347	Stabilized grade, prevents carbide precipitation
347 FeHp	E347-16		High-performance stainless steel electrode of class E 347-16 for welding stabilized Cr Ni alloys
66	E410-15		Low hydrogen electrode for corrosion and heat-resistant 14% Cr-steels
1915 HST			Low hydrogen, fully austenitic electrode with 0% ferrite content
1925			Extremely corrosion-resistant to phosphoric and sulfuric acids
68 Hcb	E310 Cb	ER310 Cb	For high heat applications and joining steels to stainless steel
2535 NbSn			Electrode is a lime-type special electrode and is used for surfacing and joining heat-resistant base metals, especially cast steel
E 330-16	E330-16		Excellent for welding furnace parts
6805			For welding of base material 17-4 Ph
6808 Mo			Rutile lime-type austenitic-ferritic electrode with low carbon content suited for joining and surfacing on corrosion-resistant steels and cast steel type with austenitic-ferritic structure (Duplex-steels)
6809 Mo			Rutile-basic austenitic-ferritic electrode with low carbon content suited for joining and surfacing on corrosion-resistant steels and cast steel types with an austenitic-ferritic structure (Duplex-steels)

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TABLE 28-6 Stainless Steel Electrodes, Filler Metals, and Wires

Aluminum and Aluminum Alloys

The AWS specifications for aluminum and aluminum alloy filler metals are A5.3 for covered arc welding electrodes and A5.10 for bare welding rods and electrodes. Filler metal classified within the A5.3 uses the atomic symbol Al, and in the A5.10 the prefix ER is used with the Aluminum Association number for the alloy, **Table 28-7**.

Aluminum-Covered Arc Welding Electrodes

Al-2 and Al-43 The aluminum electrodes do not use the letter *E* before the electrode number. Aluminum-covered arc welding electrodes are designed to weld with DCEP polarity. These electrodes can be used on thin or thick sections, but thick sections must be preheated to between 300°F (150°C) and 600°F (315°C). The preheating of these thick sections allows the weld to penetrate immediately when the weld starts. Aluminum arc welding electrodes can be used on 2024, 3003, 5052, 5154, 5454, 6061, and 6063 aluminum. When welding on aluminum, a thin layer of surface oxide may not prevent welding. Thicker oxide layers must be removed mechanically or chemically. The back of the weld can be supported by carbon plates or carbon paste. To prevent excessive penetration, most aluminum arc welding electrodes can also be used for **oxyfuel (RG)** gas welding of aluminum.

Base Metal	319 355	43 356	214	6061 6063 6151	5456	5454	5154 5254	5086	5083	5052 5652	5005 5050	3004	1100 3003	1060
1060	4145 4043 4047	4043 4047 4145	4043 5183 4047	4043 4047	5356 4043	4043 5183 4047	4043 5183 4047	5356 4043	5356 4043	4043 4047	1100 4043	4043	1100 4043	1260 4043 1100
1100 3003	4145 4043 4047	4043 4047 4145	4043 5183 4047	4043 4047	5356 4043	4043 5183 4047	4043 5183 4047	5356 4043	5356 4043	4043 5183 4047	4043 5183 5356	4043 5183 5356	1100 4043	
3004	4043 4047	4043 4047	5654 5183 5356	4043 5183 5356	5356 5183 5556	5654 5183 5356	5654 5183 5356	5356 5183 5556	5356 5183 5556	4043 5183 4047	4043 5183 5356	4043 5183 5356		
5005 5050	4043 4047	4043 4047	5654 5183 5356	4043 5183 5356	5356 5183 5556	5654 5183 5356	5654 5183 5356	5356 5183 5556	5356 5183 5556	4043 5183 4047	4043 5183 5356			
5052 5652	4043 4047	4043 5183 4047	5654 5183 5356	5356 5183 4043	5356 5183 5556	5654 5183 5356	5654 5183 5356	5356 5183 5556	5356 5183 5556	5654 5183 4043				
5083	NR	5356 4043 5183	5356 5183 5556	5356 5183 5556	5183 5356 5556	5356 5183 5556	5356 5183 5556	5356 5183 5556	5183 5356 5556					
5086	NR	5356 4043 5183	5356 5183 5556	5356 5183 5556	5356 5183 5556	5356 5183 5554	5356 5183 5554	5356 5183 5556						
5154 5254	NR	4043 5183 4047	5654 5183 5356	5356 5183 4043	5356 5183 5554	5654 5183 5356	5654 5183 5356							
5454	4043 4047	4043 5183 4047	5654 5183 5356	5356 5183 4043	5356 5183 5554	5554 4043 5183								
5456	NR	5356 4043 5183	5356 5183 5556	5356 5183 5556	5556 5183 5356									
6061 6063 6151	4145 4043 4047	4043 5183 4047	5356 5183 4043	4043 5183 4047										
214	NR	4043 5183 4047	5654 5183 5356											
43 356	4043 4047	4145 4043 4047												
319 355	4145 4043 4047													

Note: First filler alloy listed in each group is the all-purpose choice. NR means that these combinations of base metals are not recommended for welding.

Thermacote Welco

TABLE 28-7 Recommended Filler Metals for Joining Different Types of Aluminum to the Same Type or a Different Type of Aluminum

Aluminum Bare Welding Rods and Electrodes

ER1100 1100 aluminum has the lowest percentage of alloy agents of all of the aluminum alloys, and it melts at 1215°F (657°C). The filler wire is also relatively pure. ER1100 produces welds that have good corrosion resistance and high ductility, with tensile strengths ranging from 11,000 to 17,000 psi. The weld deposit has a high resistance to cracking during welding. This wire can be used with OFW, GTAW, and GMAW. Preheating to 300°F (148°C) to 350°F (176°C) is required for GTA welding on plate or pipe 3/8 in. (10 mm) and thicker to ensure good fusion. Flux is required for OFW. For items such as food containers, food-processing equipment, storage tanks, and heat exchangers, 1100 aluminum is commonly used. ER1100 can be used to weld 1100 and 3003 grade aluminum.

ER4043 ER4043 is a general-purpose welding filler metal. It has 4.5% to 6.0% silicon added, which lowers its melting temperature to 1155°F. The lower melting temperature helps promote a free-flowing molten weld pool. The welds have high ductility and a high resistance to cracking during welding. This wire can be used with OFW, GTAW, and GMAW. Preheating to 300°F (148°C) to 350°F (176°C) is required for GTA welding on plate or pipe 3/8 in. (10 mm) and thicker to ensure good fusion. Flux is required for OFW. ER4043 can be used to weld on 2014, 3003, 3004, 4043, 5052, 6061, 6062, and 6063 and cast alloys 43, 355, 356, and 214.

ER5356 ER5356 has 4.5% to 5.5% magnesium added to improve the tensile strength. The weld has high ductility but only an average resistance to cracking during welding. This wire can be used for GTAW and GMAW. Preheating to 300°F (148°C) to 350°F (176°C) is required for GTA welding on plate or pipe 3/8 in. (10 mm) and thicker to ensure good fusion. ER5356 can be used to weld on 5050, 5052, 5056, 5083, 5086, 5154, 5356, 5454, and 5456.

ER5556 ER5556 has 4.7% to 5.5% magnesium and 0.5% to 1.0% manganese added to produce a weld with high strength. The weld has high ductility and only average resistance to cracking during welding. This wire can be used for GTAW and GMAW. Preheating to 300°F (148°C) to 350°F (176°C) is required for GTA welding on plate or pipe 3/8 in. (10 mm) and thicker to ensure good fusion. ER5556 can be used to weld on 5052, 5083, 5356, 5454, and 5456.

Special-Purpose Filler Metals

ENi The nickel arc welding electrodes are designed to be used with AC or DCEP polarity. These arc welding electrodes are used for cast iron repair. The carbon in cast iron will not migrate into the nickel weld metal, thus preventing cracking and embrittlement. The cast iron may or may not be preheated. A very short arc length and a fast travel rate should be used with these electrodes.

ECuAl The aluminum bronze welding electrodes are designed to be used with DCEP polarity. This welding electrode has copper as its major alloy. The aluminum content is at a much lower percentage. Iron is usually added but at a percentage that is very low. These electrodes are sometimes referred to as arc brazing electrodes, although this is not an accurate description. Stringer beads and a short arc length should be used with these electrodes. Aluminum bronze welding electrodes are used for overlaying bearing surfaces; welding on castings of manganese, bronze, brass, or aluminum bronze; or assembling dissimilar metals.

Surface and Buildup Electrode Classification

Hardfacing or wear-resistant electrodes are the most popular special-purpose electrodes; however, there are also cutting and brazing electrodes. Specialty electrodes may be identified by manufacturers' trade names. Most manufacturers classify or group hardfacing or wear-resistant electrodes according to their resistance to impact, abrasion, or corrosion. Occasionally, electrode resistance to wear at an elevated temperature is listed. One electrode may have more than one characteristic or type of service listed.

EFeMn-A The EFeMn-A electrodes are designed to be used with AC or DCEP polarity. This electrode is an impact-resistant welding electrode. It can be used on hammers, shovels, and spindles and in other similar applications.

ECoCr-C The ECoCr-C electrodes are designed to be used with AC or DCEP polarity. This electrode is a corrosion- and abrasion-resistant welding electrode. It also maintains its resistance at elevated temperatures. ECoCr-C is commonly used for engine cams, seats and valves, chainsaw bars, bearings, and dies.

Magnesium Alloys

The joining of magnesium alloys by torch welding or brazing is possible without a fire hazard because the melting point of magnesium is 1202°F (651°C) to 858°F (459°C) below its boiling point, where magnesium may start to burn.

ER AZ61A The ER AZ61A filler metal can be used to join most magnesium wrought alloys. This filler has the best weldability and weld strength for magnesium alloys AZ31B, HK31A, and HM21A.

ER AZ92A The ER AZ92A filler metal can be used on cast alloys Mg-Al-Zn and AM 100A. This filler metal has somewhat higher resistance to cracking.

HYDROGEN EMBRITTLEMENT

Hydrogen embrittlement can be a major problem in high-strength steels. Chapter 26 covers the problems hydrogen can cause in steels. The following steps can

help to control postweld hydrogen cracking-related problems:

- Use welding filler metal and fluxes classified as low hydrogen.
- Preheat the metal to remove any moisture that may be trapped in the joint or around tack welds.
- Avoid welding when it is precipitating (raining, snowing, or sleeting).
- Follow proper storage and handling procedures for filler metal and fluxes to prevent them from becoming contaminated with sources of hydrogen such as moisture, oil, grease, or other hydrocarbons.
- Avoid welding in strong winds, which may blow the shielding gas cloud away from the molten weld pool, resulting in atmospheric moisture contaminating the weld, **Figure 28-19**.

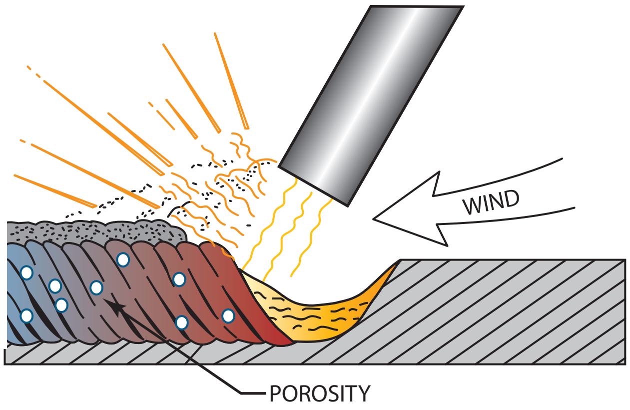


FIGURE 28-19 Wind can blow shielding away from the molten weld pool, allowing porosity to form in the weld.

Summary

Proper filler metal selection is one of the most important factors affecting the successful welding of a joint. Many factors affect the selection of the most appropriate filler metal for a job. In some cases, cost is the greatest factor, and in others it is structural strength. For example, if you were building an ultralight aircraft, you would be more concerned with strength than cost. However, if you were building an iron fence, then you might be more concerned with cost. Every application is different, so it may be a help for you to list the items you feel are most important for selecting a filler metal. This will help you select the most appropriate filler metal for your needs.

Manufacturers' literature on filler metals can be divided into two general sections. One section of the literature is technical and the other is advertisement. In the technical section, you are provided with specific information on each filler metal's operation, performance, and uses. In the advertisement section, you are provided with marketing information and claims regarding performance. Knowing the types of information in both sections will help you evaluate new material as you select filler metal.

If you are considering a large purchase of filler metals, it is advantageous for you to request samples of the various filler metals from manufacturers so that you can test their performance in your applications. Pretesting of the products in your applications will give you an opportunity to determine which filler metal is going to give you the best value for your money. It may also be necessary to qualify the filler metal for your welding certification program before you make the purchase and begin using the product.

Review

1. What groups have developed electrode identification systems?
2. What types of general information about electrodes may be given by different electrode manufacturers?
3. Define *tensile strength*.
4. What chemicals alloys are
   - **a.** considered to be contaminants to the weld metal?
   - **b.** used to increase tensile strength in the weld metal?
   - **c.** used to increase corrosion resistance?
   - **d.** used to reduce creep?
5. What should CE be used for?
6. What welding parameters should be used for a metal that has a CE of more than 0.60%?
7. What functions can the flux covering of an SMA electrode provide to the weld?
8. How does an SMA welding electrode's flux covering produce the shielding gas to protect the weld?
9. What fluxing agents act as scavengers in the molten weld pool?

10. How can an SMA welding electrode's flux help with deeper penetration?
11. What are the advantages of refractory-type stages?
12. List the things that must be considered before selecting an electrode for a specific job.
13. Why can there be more than one electrode for each classification manufactured by the same company?
14. What do the following filler metal designations stand for?
    a. E
    b. ER
    c. RG
    d. IN
15. Explain the parts of the AWS classified system for SMAW electrodes such as E7018.
16. Which SMA welding electrode(s) can be used to weld on metal that has a light covering of paint?
17. Which SMA welding electrodes are commonly used to weld on sheet metal fabrications?
18. Which SMA welding electrodes can be used with a drag technique?
19. Referring to Figure 28-8 through Figure 28-15, which electrode has the deepest penetration?
20. How is the E7018 molten weld pool protected?
21. What is the purpose of the deoxidizers in ER70S-2?
22. What alloying element used in FCA welding electrodes causes the electrode to produce centerline cracks in the weld if it is used for multipass welds?
23. What does the 15 and 16 stand for in SMA stainless steel welding electrodes?
24. What stainless steel(s) would
    a. have low creep at high temperatures?
    b. be used for food service equipment?
25. Referring to Table 28-5, what stainless steel filler metal would be selected for welding
    a. 304L stainless steel to 314 stainless steel?
    b. 321 stainless steel to 348 stainless steel?
    c. 316 stainless to mild steel?
26. What would be a stainless steel filler metal for welding on furnace parts?
27. What forms the basis for the AWS identification system for nonferrous covered electrodes?
28. Why must thick sections of aluminum be preheated before an Al-2 electrode is used for welding?
29. For what types of items would the purest aluminum alloy be used?
30. What are aluminum *arc brazing electrodes* used for?
31. How do most manufacturers classify or group hardfacing or wear-resistant electrodes?

Chapter 29

Welding Automation and Robotics

OBJECTIVES

After completing this chapter, the student should be able to

- explain the difference among manual (MA), semiautomatic (SA), machine (ME), automatic (AU), and automated welding.
- list the major factors to be considered in establishing a robotic welding station.
- list robotic safety considerations.
- explain the need for interaction among various components of robotic workstations.

KEY TERMS

automated joining

automatic joining

computer-aided design (CAD)

computer-aided manufacturing (CAM)

cycle time

industrial robot

machine joining

manual joining

pick and place

semiautomatic joining

sensors

work cell

x-axis

y-axis

z-axis

INTRODUCTION

The use of technology to reduce production time, increase output, and reduce costs began as early as the 1920s. The automotive industry first used the automatic welding process to produce high-quality welded swing-arm supports and other parts. The process used a continuous-feed, unshielded, bare wire. Since that time, advances in automatic welding technology have continued to take place.

In the 1960s, American technology produced the first industrial robots. The first industrial robots were used by the nuclear industry to handle radioactive materials. These early units were mainly **pick and place** robots used to move material, with little repetitive accuracy required. During the 1970s, computers were applied in increasing numbers by large industry to serve as intelligent controllers for automation. By the 1980s, the decreasing cost of computers and advancements in robotics had made this technology possible, even for small businesses.

More and more modern businesses are using **computer-aided design (CAD)** to improve products. CAD technology can help in selecting materials, specifying thicknesses, and locating supports to ensure good engineering design of products. **Computer-aided**

manufacturing (CAM) can then be used to improve production. CAM technology can aid in selecting assembly methods, planning the product flow through the manufacturing steps, and scheduling the various operations to reduce the actual production costs.

Computers and microprocessors assist modern industry in producing high-quality products with a minimum waste of materials and time. The use of high technology to monitor part flow through production alerts management to potential problem areas before they cause slowdowns, lost manufacturing time, and increased costs, as well as possible hazardous situations.

Automation is revolutionizing industry worldwide. Some manufacturing plants using robots and other automatic equipment require only supervisory personnel to manage large portions of the production. These facilities are only the beginning.

Many workers whose jobs are modernized by automation find that there are new and more technical opportunities for operating, maintaining, designing, and installing automated equipment and robots. Skilled technicians are needed to set up and operate such automatic manufacturing equipment. The technician needs to understand the manufacturing processes, including welding, to ensure that the operating guidelines established will work consistently. Most robot manufacturers recommend that a highly skilled welder should be selected to operate the robot. It is much easier to train a welder to operate the robot than it is to train a computer technician to make good welds.

In welding applications, the increased use of robots, however, will never replace the tremendous need for skilled welders. Welders will always be needed to produce high-quality welds in production and maintenance in locations that are too restricting for robotics.

Students who have mastered hands-on welding techniques and those who understand the various automated welding procedures will have the advantage when seeking either type of employment opportunity.

This chapter gives the welding student a general overview of automatic welding processes and robotics with guidelines on implementing automation in welding applications.

MANUAL JOINING PROCESS

A **manual joining** process is one that is completely performed by hand. The welder controls all of the manipulation, rate of travel, joint tracking, and the rate at which filler metal is added to the weld. The manipulation of the electrode or torch in a straight line or oscillating pattern affects the size and shape of the weld, **Figure 29-1**. The manipulation pattern may also be used to control the size of the weld pool during out-of-position welding. The rate of travel or speed at which the weld progresses along the joint affects the width, reinforcement, and penetration of the weld, **Figure 29-2**. The placement or location of the weld bead within the weld joint affects the strength, appearance, and possible acceptance of the joint. The rate at which filler metal is added to the weld affects the reinforcement, width, and appearance of the weld, **Figure 29-3**.

The most commonly used manual arc (MA) welding process is shielded metal arc welding (SMAW). This process was described in Section 2 of this text. The flexibility the welder has in performing the weld makes this process one

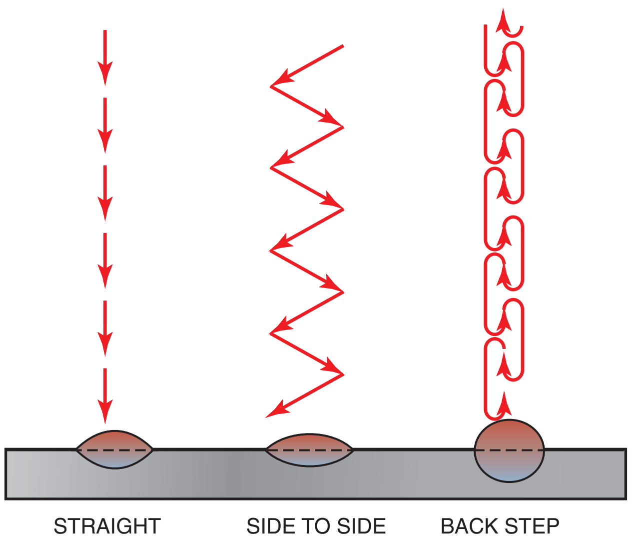


FIGURE 29-1 The electrode manipulation affects the size and shape of the weld bead.

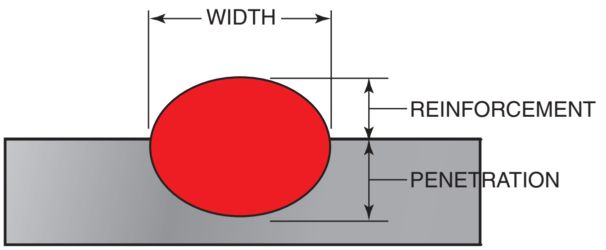


FIGURE 29-2 The travel rate of the weld affects width, reinforcement, and penetration of the weld bead.

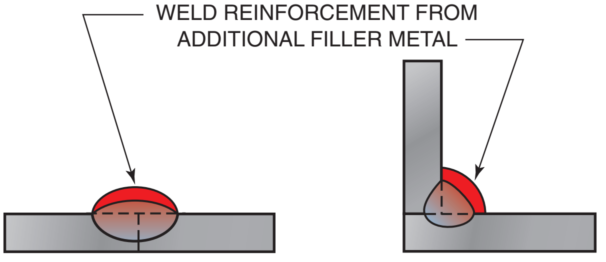


FIGURE 29-3 Addition of filler metal.

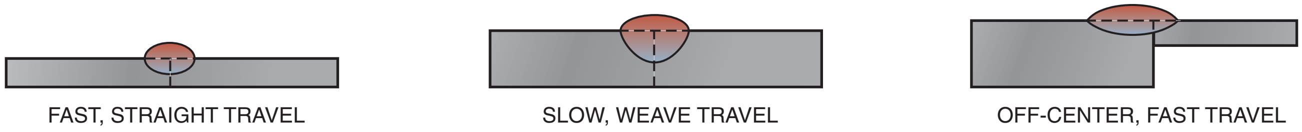


FIGURE 29-4 Controlling weld bead size by adjusting welding parameters.

Arc
Shielded metal arc welding (SMAW)
Gas tungsten arc welding (GTAW)
Gas
Oxyacetylene welding (OAW)
Brazing
Torch brazing (TB)

TABLE 29-1 Manual Joining Processes

of the most versatile. By changing the manipulation, rate of travel, or joint tracking, the welder can make an acceptable weld on a variety of material thicknesses, **Figure 29-4**.

The most commonly used manual arc welding, gas welding, and brazing processes are listed in **Table 29-1**.

SEMIAUTOMATIC JOINING PROCESSES

A **semiautomatic joining** process is one in which the filler metal is fed into the weld automatically. Most other functions are controlled manually by the welder. The addition of filler metal to the weld by an automatic wire-feeder system enables the welder to increase the uniformity of welds, productivity, and weld quality. The distance of the welding gun or torch from the work remains constant. This gives the welder better manipulative control as compared to, for example, shielded metal arc welding, in which the electrode holder starts at a distance of 14 in. (356 mm) from the work. This distance exaggerates the slightest accidental movement made during the first part of the weld, **Figure 29-5**. In the SMAW process, the electrode holder must be lowered steadily as the weld progresses to feed the electrode and maintain the correct arc length, **Figure 29-6**.

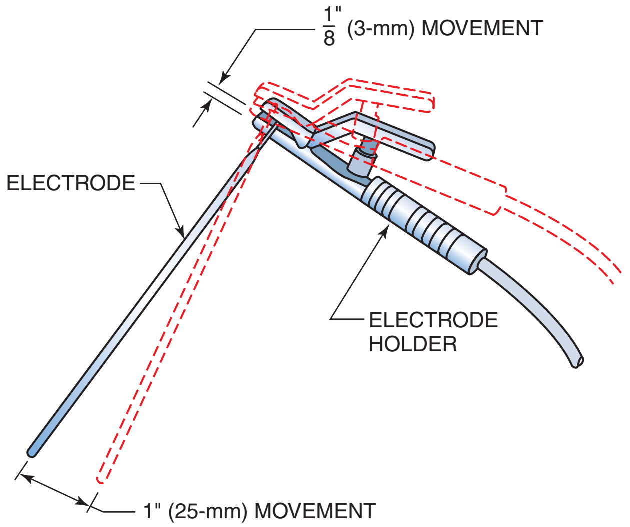


FIGURE 29-5 A 1/8-in. (3-mm) movement of the electrode holder results in a 1-in. (25-mm) movement of the electrode at the surface of the work.

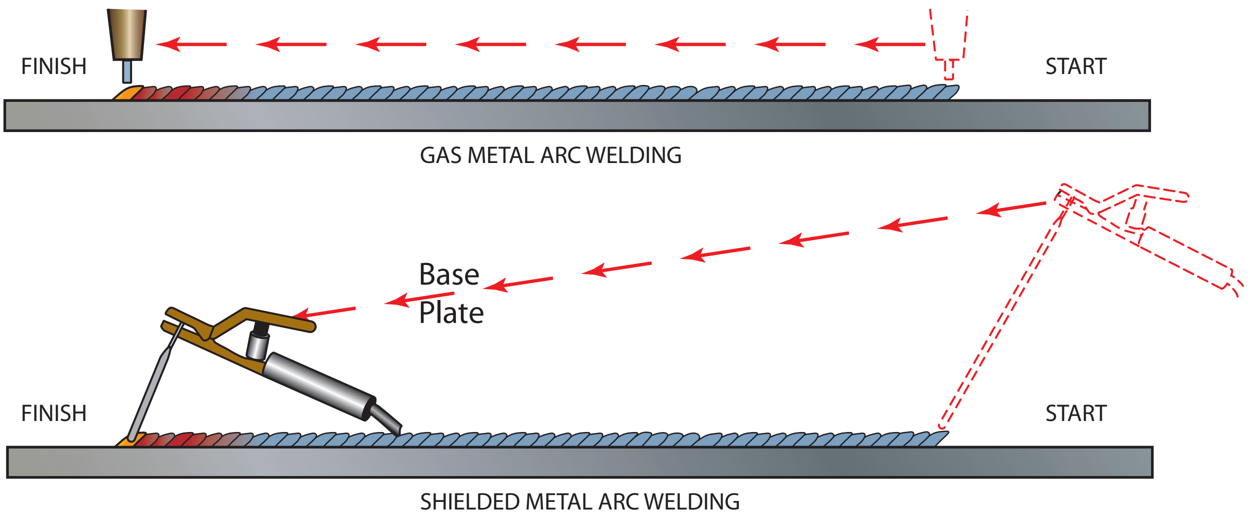


FIGURE 29-6 In GMAW, the torch height remains constant above the work surface. In SMAW, the height of the electrode holder steadily decreases from the beginning to the end of the weld.

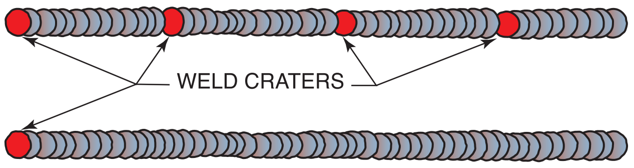


FIGURE 29-7 Fewer weld craters occur in continuous welding.

Arc
Gas metal arc welding (GMAW)
Flux cored arc welding (FCAW)
Submerged arc welding (SAW)
Gas tungsten arc welding (GTAW)
Cold-hot wire feed

TABLE 29-2 Semiautomatic Joining Processes

This constant changing of the distance above the work causes the welder to shift body position frequently. This change, too, may affect the consistency of the weld.

Because the filler metal is being fed from a large spool, the welder does not have to stop welding to change filler electrodes or filler metal. SMA electrodes cannot be used completely because they have a waste stub of approximately 2 in. (51 mm). This waste stub represents approximately 15% of the filler metal that must be discarded. The frequent stopping for rod and electrode changes, followed by restarting, wastes time and increases the number of weld craters. These craters are often a source of cracks and other discontinuities, **Figure 29-7**. In some welding procedures, each weld crater must be chipped and ground before the weld can be restarted. These procedures can take up to 10 minutes—time that can be used for welding in a semiautomatic welding process.

The most commonly used semiautomatic arc (SA) welding processes are gas metal arc welding (GMAW) and flux cored arc welding (FCAW). This process was fully described in Section 4. **Table 29-2** lists several other semiautomatic processes.

MACHINE JOINING PROCESSES

A **machine joining** process is one in which the joining is performed by equipment requiring the welding operator to observe the progress of the weld and make adjustments as required. The parts being joined may or may not be loaded and unloaded automatically. The operator may monitor the joining progress by watching it directly, observing instruments only, or using a combination of both methods. Adjustments in travel speed, joint tracking, work-to-gun or work-to-torch distance, and current settings may be needed to ensure that the joint is made according to specifications.

The work may move past a stationary welding or joining station, **Figure 29-8**, or it may be held stationary and the welding machine moves on a beam or track along the joint, **Figure 29-9**. On some large machine welds, the operator may ride with the welding head along the path of the weld. During the assembly of the external fuel tanks used for the space shuttle, two operators were required for a few of the machine welds. One operator watched the root side of the weld while the other observed the face side of the weld. They were able to communicate with each other so that any needed changes could be made.

To minimize adjustments during machine welds, a test weld is often performed just before the actual weld is produced. This practice weld helps increase the already high reliability of machine welds.

AUTOMATIC JOINING PROCESSES

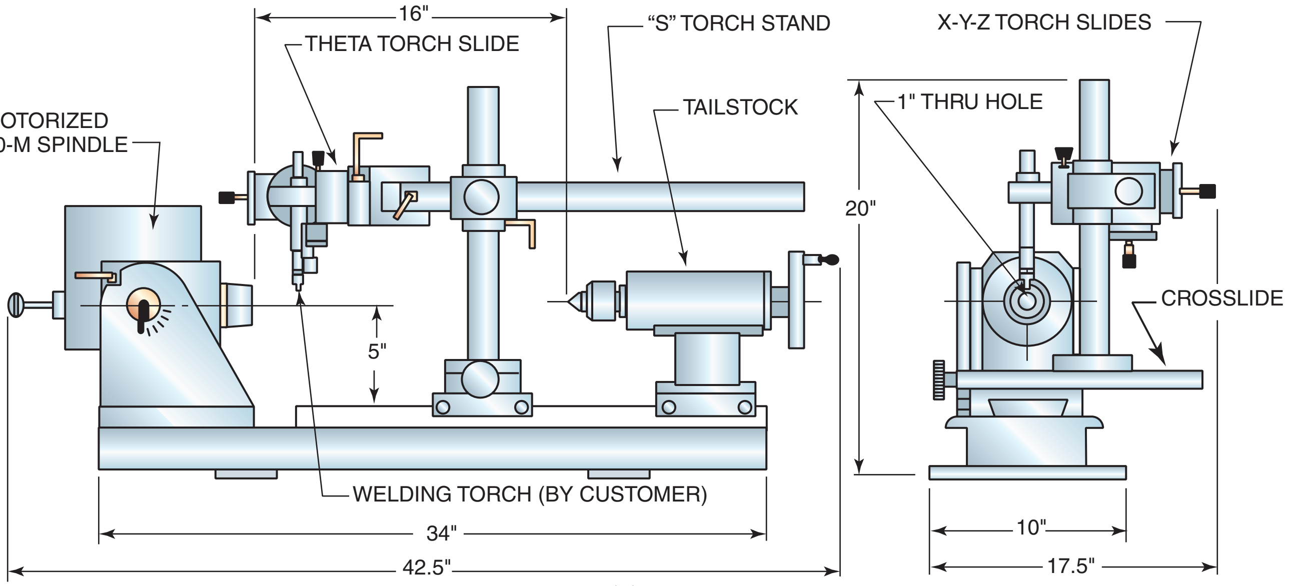
An **automatic joining** process is a dedicated process (designed to do only one type of welding on a specific part) that does not require adjustments to be made by the operator during the actual welding cycle. All operating guidelines are preset, and parts may or may not be loaded or unloaded by the operator. Automatic equipment is often dedicated to one type of product or part. A large investment is usually required in jigs and fixtures used to hold the parts to be joined in the proper alignment. The operational cycle can be controlled mechanically or numerically (computer). The cycle may be as simple as starting and stopping points, or it may be more complex. A more complex cycle may include steps such as prepurge time, hot start, initial current, pulse power, downslope, final current, and postpurge time, **Figure 29-10**.

Automatic welding or brazing is best suited to large-volume production runs because of the expense involved in special jigs and fixtures.

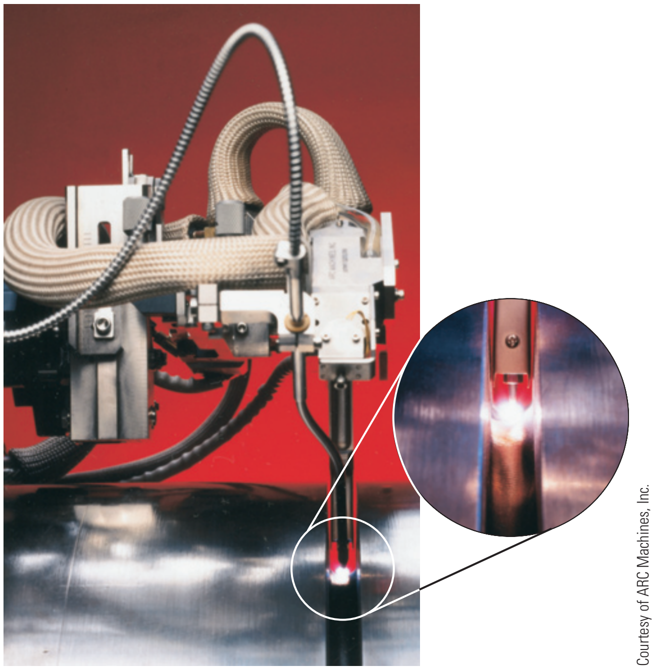
AUTOMATED JOINING

Automated joining processes are similar to automatic joining except that they are flexible and more easily adjusted or changed. Unlike automatic joining, there is no dedicated machine for each product. The equipment can be easily adapted or changed to produce a wide variety of high-quality welds.

The industrial robot is rapidly becoming the main component in automated welding or joining stations. The welding or joining cycles are often controlled by computers or microprocessors. The flexibility provided by automated workstations makes it possible for even small companies with limited production runs to invest in automated equipment. The equipment is controlled by programs, or a series of machine commands expressed in numerical codes, that direct the welding, cutting, assembling, or any



(A)



(B)

FIGURE 29-8 Two precision bench-welding systems.

other activities. The programs can be stored and quickly changed. Some systems can store and retrieve many different programs internally. Other systems are controlled by a host computer. Both types of systems can speed up production when frequent changes are required.

INDUSTRIAL ROBOTS

An **industrial robot** is a reprogrammable, multifunctional manipulator designed to move material, parts, tools, or specialized devices through variable programmed motions for the performance of a variety of tasks. Industrial robots are primarily powered by electric stepping motors, hydraulics, or pneumatics and are controlled by a program.

Robots can be used to perform a variety of industrial functions, including grinding, painting, assembling, machining, inspecting, flame cutting, product handling, and welding.

Robots range in size and complexity from small desktop units capable of lifting only a few ounces (grams) to large floor models capable of lifting tons.

FIGURE 29-9 Automatic GTA machine welding along the seam of a stationary pipe.

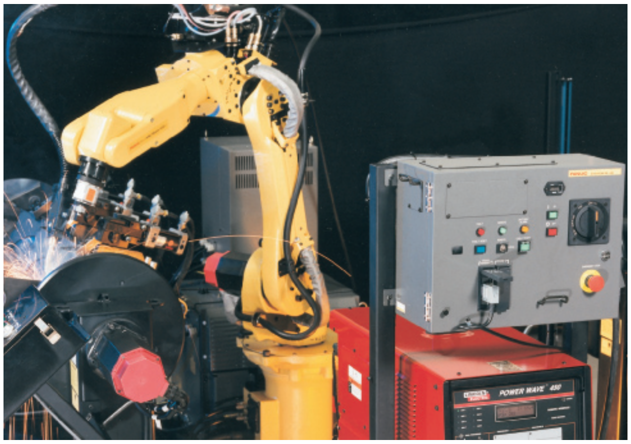


FIGURE 29-11 Machine axes.

Most robots can perform movements in three basic directions: longitudinal (**x-axis**), transverse (**y-axis**), and vertical (**z-axis**), **Figure 29-11**. The tool end of the robot arm may also be jointed so that it can tilt and rotate, **Figure 29-12**.

The robot may be used with other components to increase production and the flexibility of the system. A computer or microprocessor can synchronize the robot's operation to positioners, conveyors, automatic fixtures, and other production machines. Parallel or multiple workstations increase the duty cycle (the fraction of time during which welding or work is being done) and reduce **cycle time** (the period of time from starting one operation to starting another), **Figure 29-13**. Parts can be loaded or unloaded by the operator at one station while the robot welds at another station.

Robot Programming

The programming that directs the robot through the desired welding or cutting path can be accomplished in any number of ways. Early robot programming took a great deal of time and involved a lot of trial and error. Trial and error is the process of first programming and then making a weld to see if it works. The results are examined,

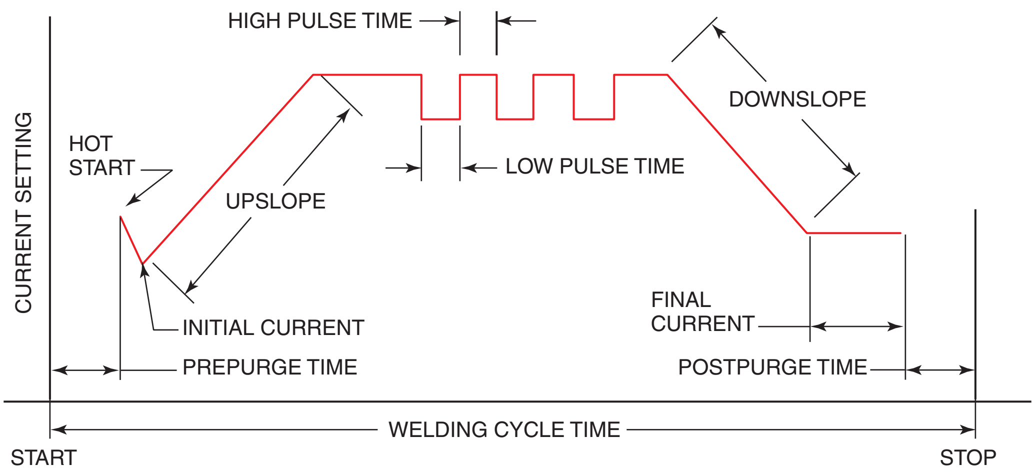


FIGURE 29-10 Typical GTAW automatic welding program.

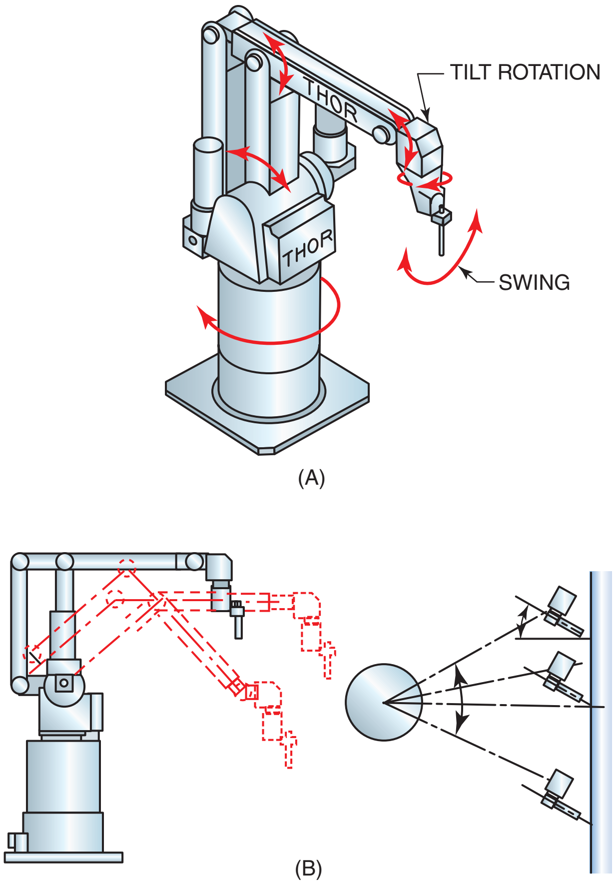


FIGURE 29-12 The tool end may be jointed so that it can tilt and rotate.

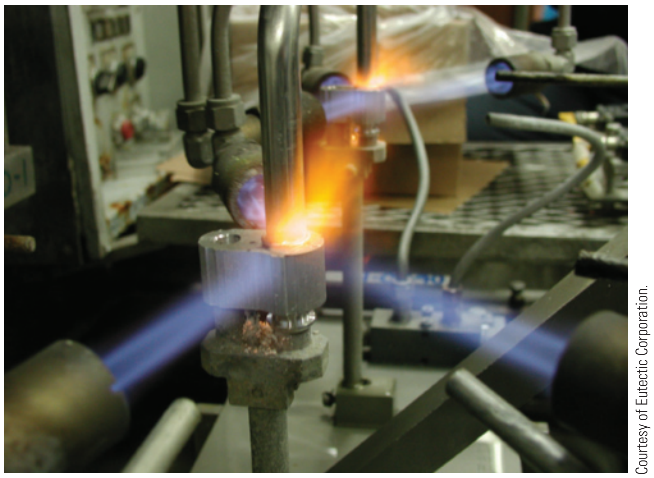


FIGURE 29-13 Rotating work table increases the work zone.

and then any needed changes are made in the programming. This process is still used by some today, but it is a lot faster because of improvements in the programming process.

With the integration of computer-aided design (CAD) to most of today's manufacturing, the robot can simply follow the weld joint design directly from the CAD program. This process is called computer-aided manufacturing (CAM). With this process, there may be only a little adjusting required by the welding technician to make the weld. Another method of programming the robot is to teach it to move its arm along the desired path. The arm can be moved through the complete cycle by physically directing its movements by hand or by using a remote control panel, **Figure 29-14**. The remote control panel allows the operator to direct the arm to the desired points along the weld path. In both cases, the robot will follow a straight line between the points established during the training session, **Figure 29-15**. A circular path or curve can be obtained by

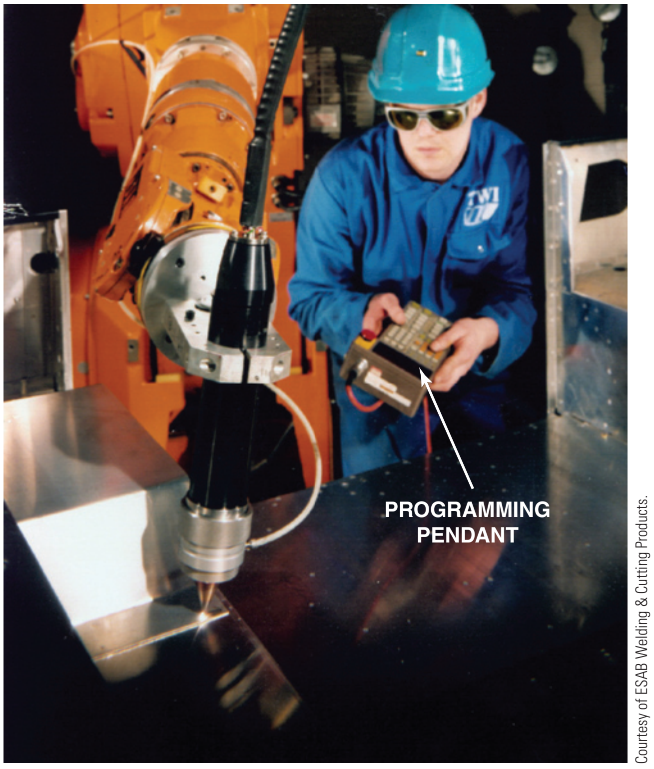


FIGURE 29-14 Remote teaching pendant for programming robot.

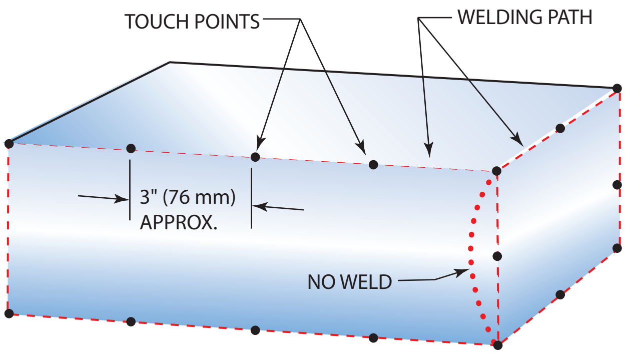


FIGURE 29-15 Straight line welds.

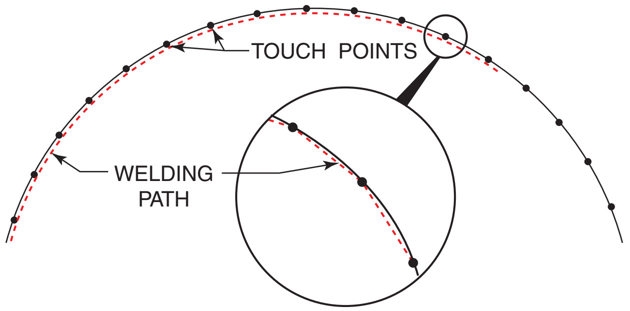


FIGURE 29-16 Curve welding path.

using teach points, **Figure 29-16**. Some units can be given the radius to be followed. A weave pattern can be added to the basic straight line weld at this time.

After the robot has been programmed by the teaching session, a test run should be made. Using a properly located part, with the welding current off, watch the robot arm to see if it follows the correct path. If the test run appears to be satisfactory, then the welding parameters are set. A part should then be welded and the welds inspected for acceptability.

Another method of programming a robot is to use computer software to produce the program. These programs allow the operator to select any number of preprogrammed operations from a screen menu. A computer simulation can then be run to ensure that the program performs the operations correctly. Feedback loops can interface the program with the robot so that if the welding head is not tracking properly, then the operator will be alerted and the robot will stop.

After the program has been tested and determined to be acceptable, it can be stored for future use. The CD, USB flash drive, and computer disc storage are the three most common storage methods. CDs are easily scratched; however, unlike computer discs, they cannot be erased accidentally, damaged, or changed by other electrical equipment. If the CDs are properly handled and stored, they can be a permanent program record. Programs stored on computer discs can be modified easily for production design changes. Care must be taken to prevent accidental erasure or damage due to the strong magnetism found around welding machines unless CDs are used.

SYSTEM PLANNING

Evaluating the need for the use of a robot and selecting a robot to meet that need is a complex process. Some of the factors that must be considered are the following:

- Present and future needs
- Parts design
- Equipment selection
- Safety

Present and Future Needs

A system using a robot can be 80% more productive than a system using manual welders. This higher rate of productivity means that there must be a market for the higher volume of product produced. Premature investment in automation can be more costly than it can be productive. A comprehensive market analysis of present and future needs must be the first step to ensure that your business is not overextended.

Parts Design

The design of the weldment must be compatible with a robotic system. The components should be selected and assembled so that the accessibility of the robot's arm and torch is not restricted, **Figure 29-17**. Although the torch can be moved along several axes, it cannot reach restricted areas as a welder can when using manual processes. Proper design and assembly sequences can reduce the amount of manual pickup welding required to complete the weldment. Mockups and CAD/CAM can be used before the robot is installed to reduce possible problems.

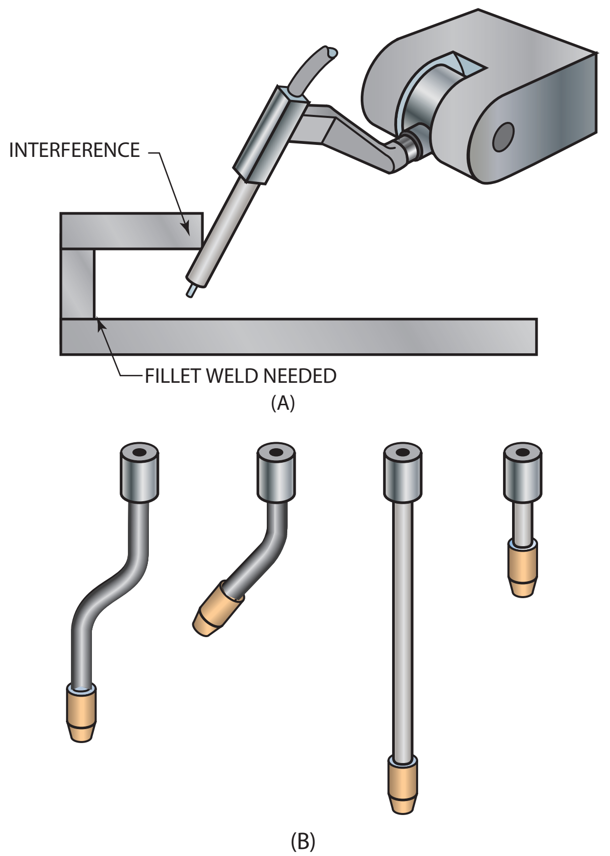


FIGURE 29-17 (A) Parts should be designed to permit access to the joint. (B) Automatic gun exchanger, which permits different gun designs to be used when needed.

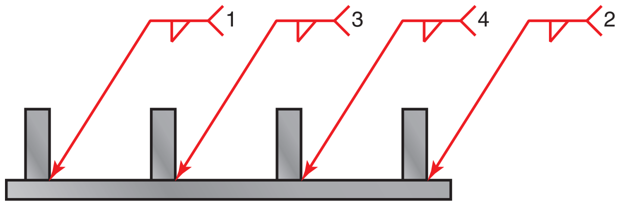


FIGURE 29-18 Staggering weld positions to prevent distortion of the workpiece.

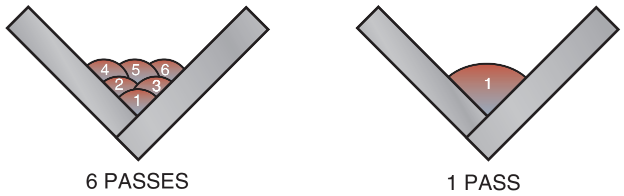


FIGURE 29-20 One large weld can be made faster and is less critical to produce.

The parts design must also take into consideration the higher heat input from the almost constant welding. This heat could result in distortion of the weldment if some compensation were not provided. One method of controlling this distortion is to stagger the weld locations, **Figure 29-18**. However, this practice means that more arm articulation (movement) is required, resulting in a slowdown in production. The best method of eliminating distortion is to use a combination of jigs, tack welds, and preset angles, **Figure 29-19**. This technique can be very successful, but it requires more initial design and setup time than other methods.

When possible, all welds should be performed in the flat position. Large weld sizes are less critical than small weld sizes in their exact location, **Figure 29-20**. Small weld sizes require better tolerances because even the slightest mislocation may be unacceptable.

Equipment Selection

The robot is the prime component in an automated **work cell** (a manufacturing unit consisting of two or more workstations), **Figure 29-21**. The selection of the system must be considered in connection with the other pieces of

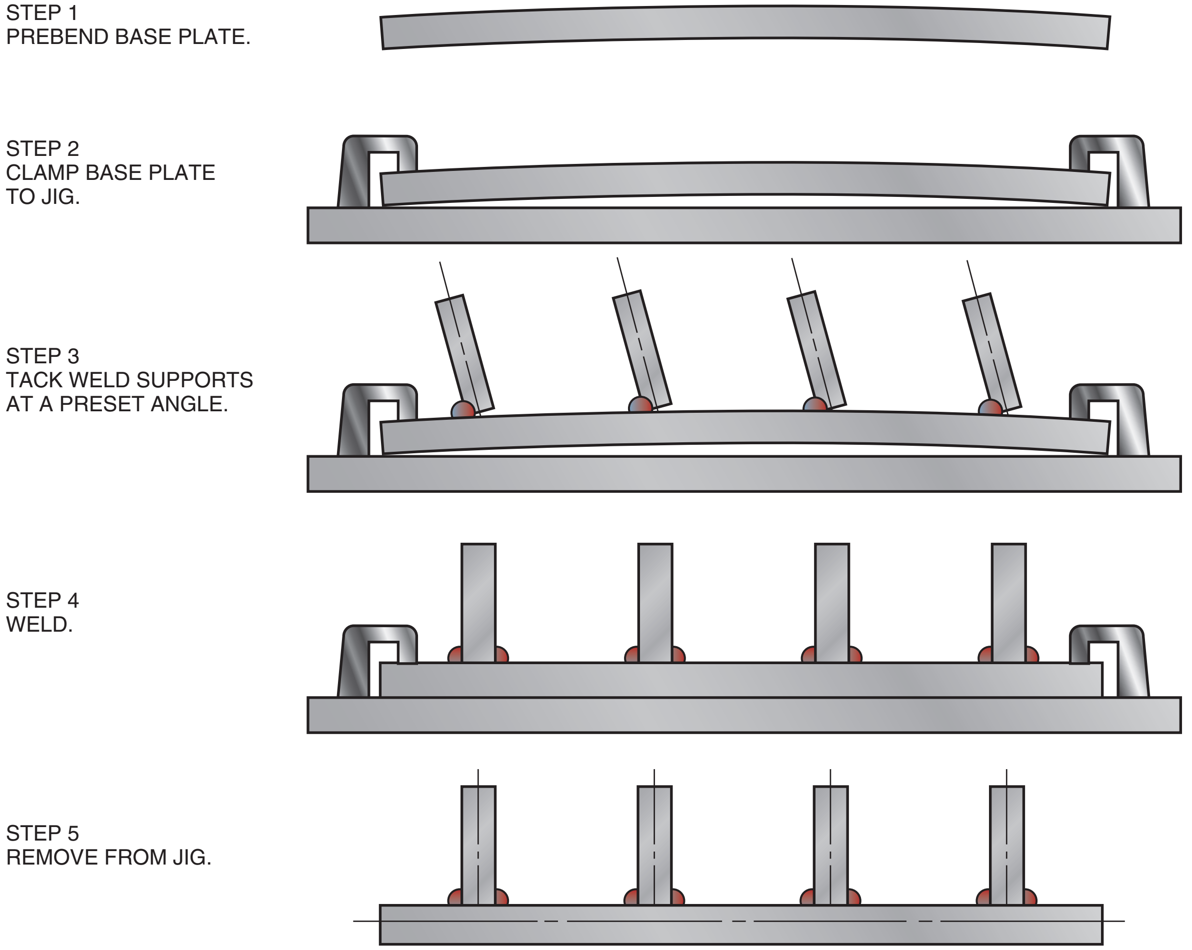


FIGURE 29-19 Suggested steps to eliminate heat distortion in completed part.

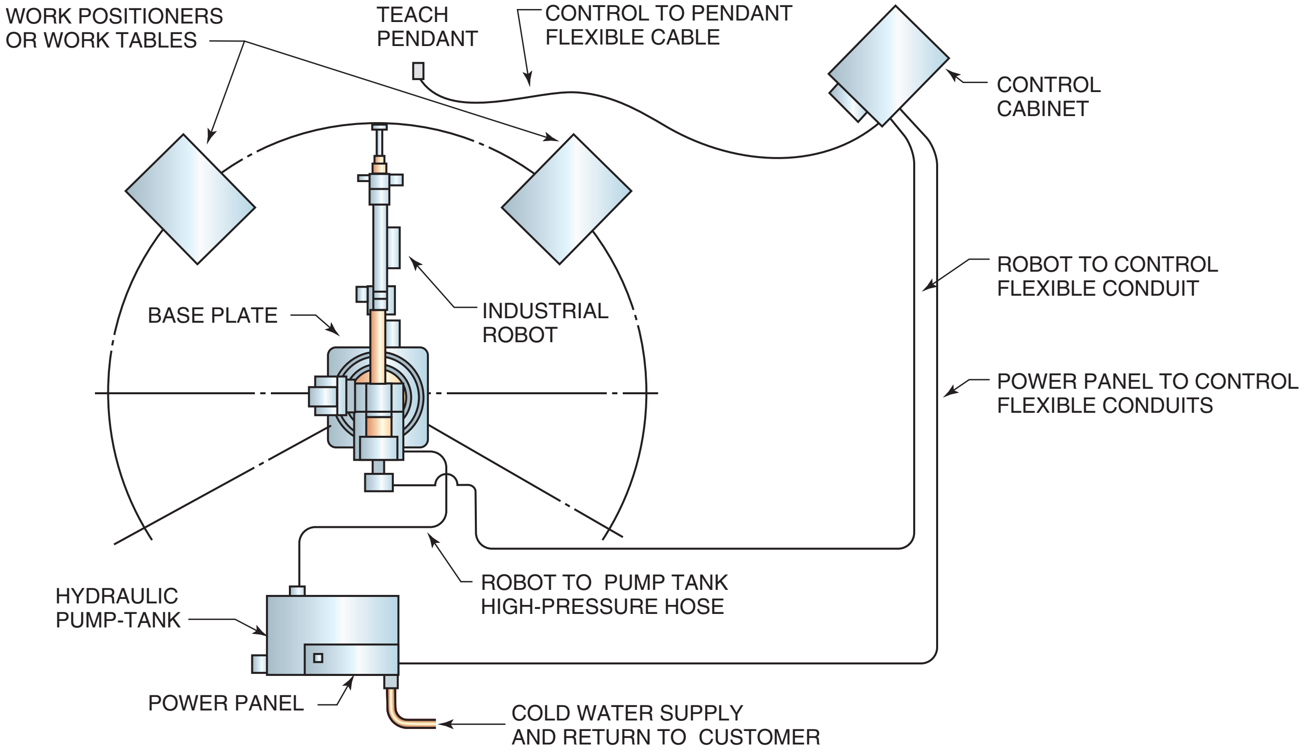


FIGURE 29-21 Typical work cell layout.

equipment being used. To obtain the most effective system, the robot, welding power supply, positioners, conveyors, and other equipment should all be computer-controlled.

The robot itself must be evaluated for its ability to work in a welding environment. Other factors of equipment selection to be considered include speeds, work zone configuration, accuracy, programmability, weave capability, and interaction capability with other equipment. The welding environment, unlike other manufacturing areas, is hot. The parts and machines in the welding environment are frequently exposed to spatter and subject to electronic noise (RF) from all arcs and high-frequency starts. Weld spatter can stick to unprotected machine surfaces, causing the arm to jam or resulting in excessive wear. Electronic noise can damage the program, interrupt input or output signals, and cause erratic operations.

The speeds at which the robot arm moves must be compatible with the welding process. The rate of movement must be constant when making a specific size weld, but travel speed will have to be varied to permit different weld sizes and positions. A higher speed during arm articulation to a new position can increase productivity.

A welding tip service station can be included to prevent spatter buildup from clogging the welding torch. The service station can include a reamer to remove spatter and an automatic spray of antispatter.

The size and configuration of the work zone depends on the number of axes and reach of the robot, **Figure 29-22A** through **D**. The articulation of the torch may limit the overall reach of the robot, **Figure 29-23A** and **B**. The use of the robot together with a rotating table or positioner can increase its effective work zone (refer to Figure 29-13).

The accuracy with which a work cycle can be repeated and the joint tolerances that can be accepted must be considered when selecting equipment. To make acceptable welds, it is important that the arm follow the same path within a few thousandths of an inch (millimeters) each time. Some units have **sensors** that track the joint even if it varies from the programmed path. This feature permits the welding of parts that otherwise might have been rejected.

Several programming options are available from robot manufacturers. The greater the programming flexibility available, the more versatile is the unit. A typical welding program cycle can include the components shown in **Figure 29-24**.

A signal from the positioner indicates that the parts are in place. The arm moves to the weld starting point and waits as preflow gas starts to flow. Both the current and wire feed are started, and a molten weld pool is established before the arm begins to move along the weld joint. At the end of the joint, the arm stops and the current and wire feed continue to fill the weld crater. The wire feed stops, followed in one second by the current to burn back the wire. Gas flow continues for postflow. During the welding cycle, the program may perform checks to ensure that the

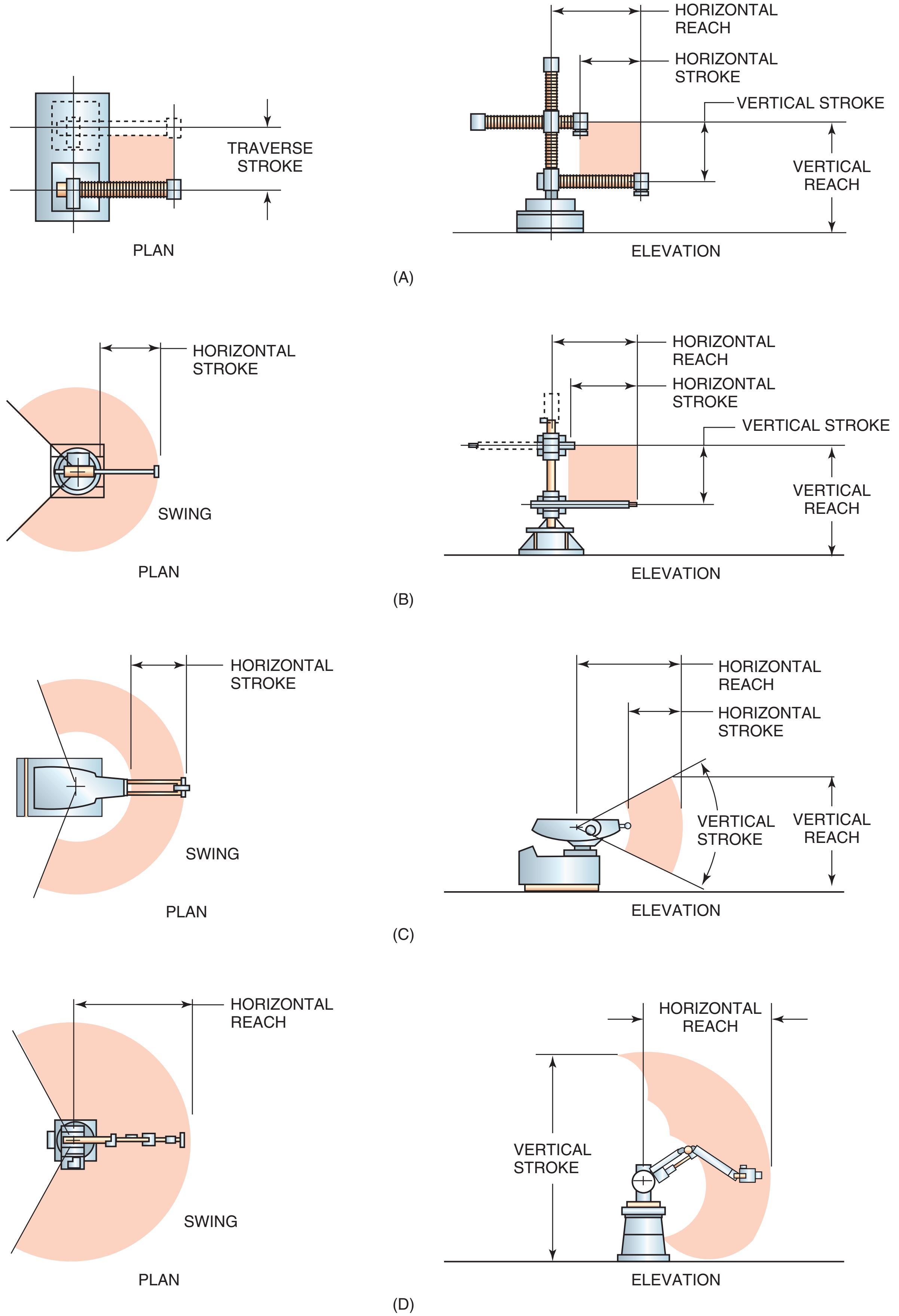


FIGURE 29-22 The work envelope for various types of robots is different: (A) rectangular coordinate robot; (B) cylindrical coordinate robot; (C) spherical coordinate robot; and (D) jointed arm robot.

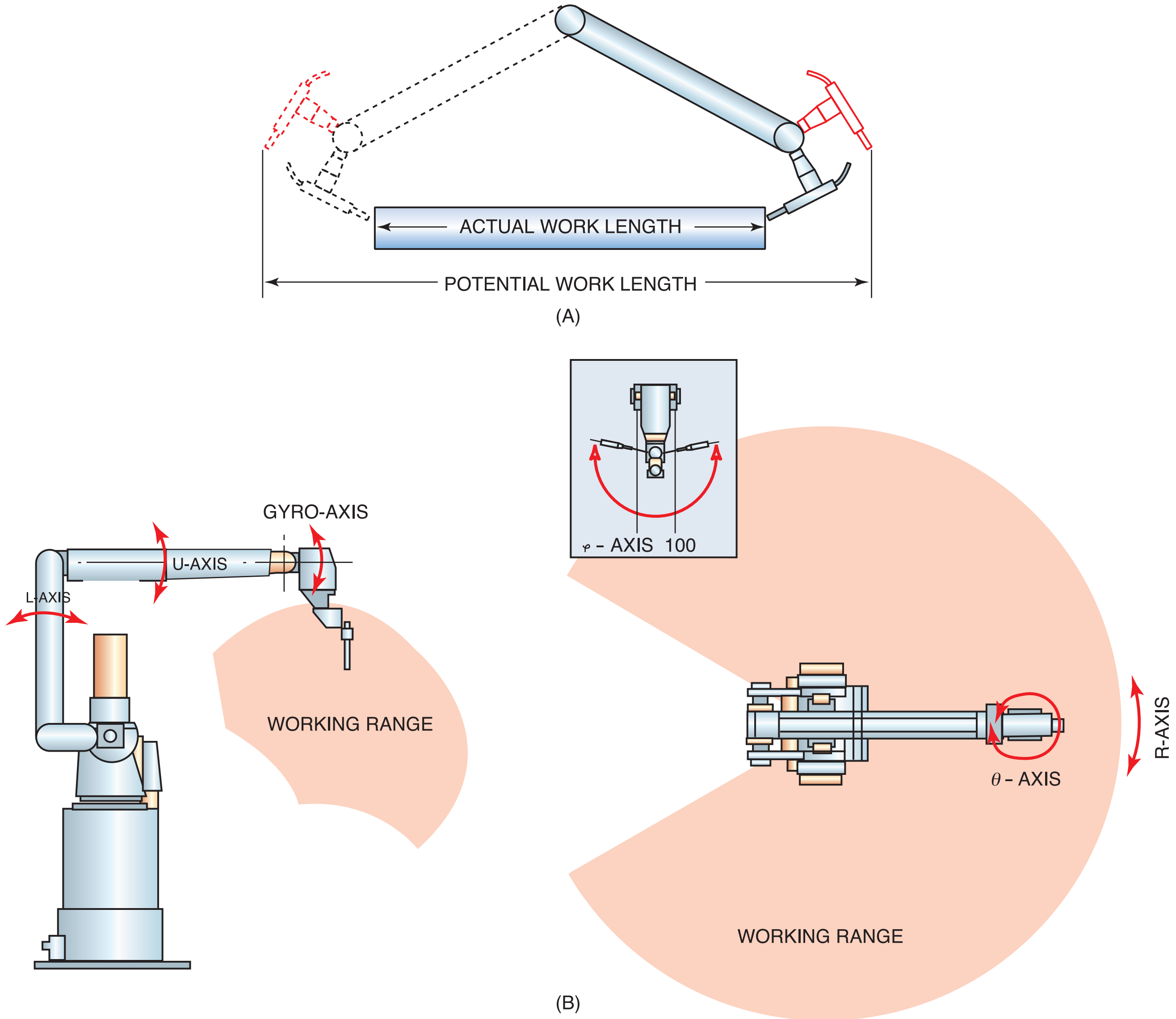


FIGURE 29-23 The actual work length and potential work length (A) often are different but must fit into the working range (B).

gas flow, voltage, amperage, and other external factors are operating correctly.

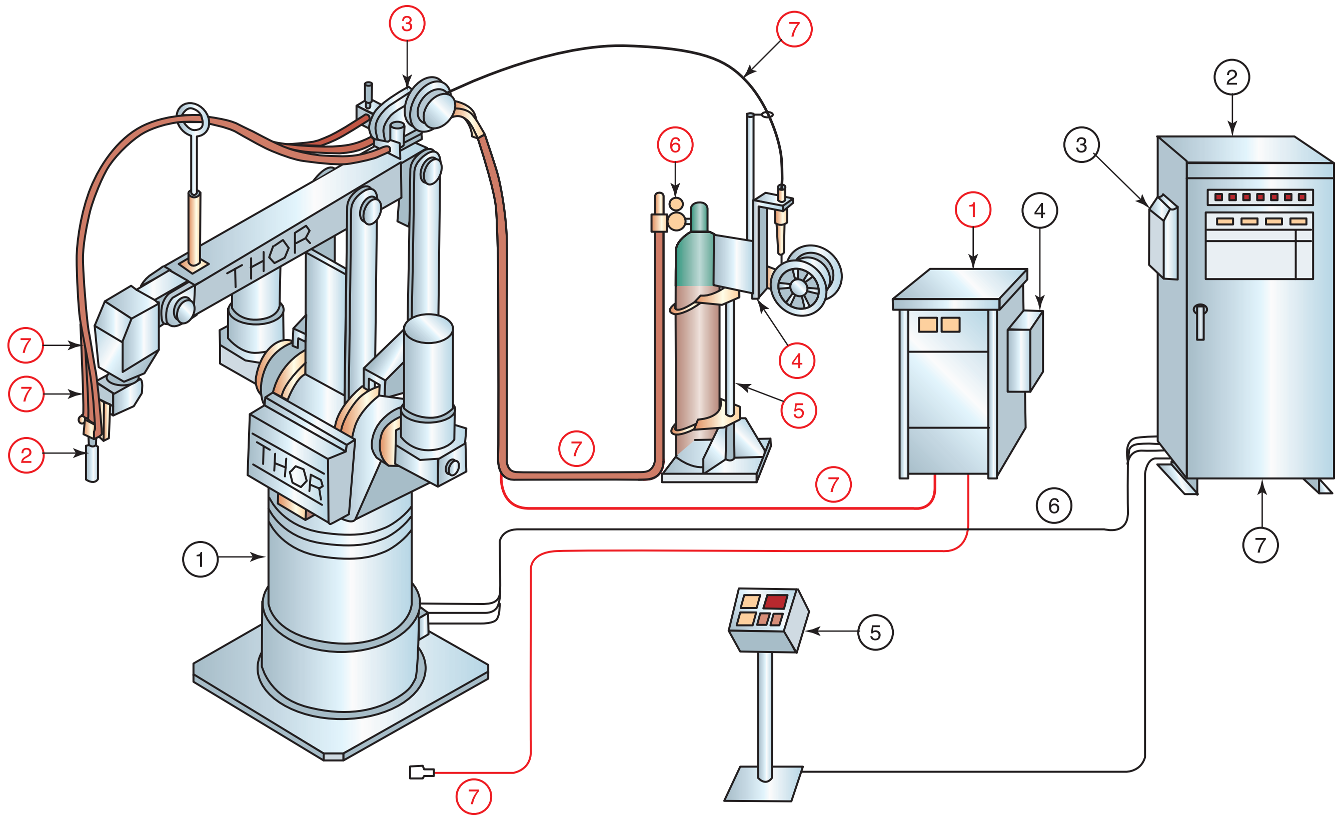
The program may also allow the torch to be manipulated in several different weave patterns, **Figure 29-25**. This feature means that large single-pass welds or out-of-position welds can be performed successfully.

To ensure that the system achieves maximum productivity, it is important for all components to be able to be remotely controlled. Preferably, it should be adjustable to various power settings. The wire feeder should have various speed settings in addition to remote starting and stopping. Sensors should provide the robot with an "arc start" signal in addition to continuous monitoring of voltage and amperage readings. Product moving and positioning equipment should have sensors to indicate that the part is "in position" and ready for welding. Safety sensors should immediately stop all movement of equipment if unauthorized persons are in the work zone.

Safety

The following precautions are recommended for the use of automatic welding equipment and robots:

- All personnel should be instructed in the safe operation of the robot.
- All personnel should be instructed in the location of an emergency power shutoff.



SYMBOL	WELDING ROBOT
1	ARC WELDING ROBOT
2	ROBOT CONTROL UNIT
3	TEACHING BOX
4	WELDING SIGNAL UNIT
5	CONTROL BOX
6	CONTROL CABLES
7	EXTERNAL MEMORY UNIT (LOCATED INSIDE OF THE ROBOT CONTROL UNIT)

SYMBOL	WELDING EQUIPMENT
1	WELDING POWER SUPPLY
2	WELDING TORCH
3	WIRE FEEDER
4	WIRE REEL UNIT
5	STAND FOR GAS CYLINDER
6	CO_2 GAS FLOW REGULATOR
7	CABLE AND HOSE ASSEMBLY

FIGURE 29-24 Computerized arc welding robot for gas shielded arc welding.

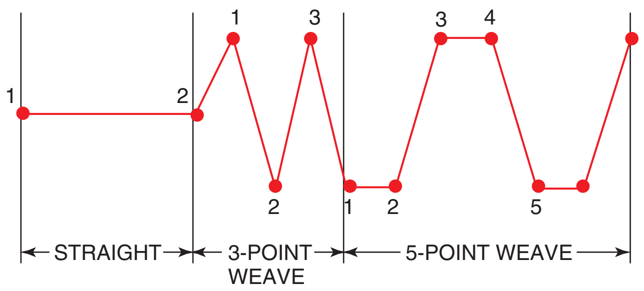


FIGURE 29-25 Weave patterns.

- The work area should be restricted to authorized persons only.
- The work area should have fences, gates, or other restrictions to prevent access by unauthorized personnel.
- Sensors should be mounted around the floor and work area to stop all movement when unauthorized personnel are detected in the work area during the operation.
- The arc welding light should be screened from other work areas.
- A breakaway toolholder should be used in case of accidental collision with the part, **Figure 29-26**.
- A signal should sound or flash before the robot starts moving.

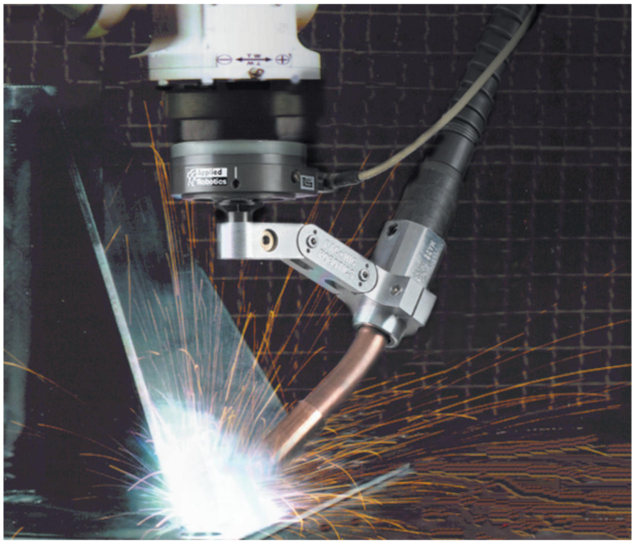


FIGURE 29-26 When using automatic welding equipment and robots, a breakaway toolholder should be used.

FUTURE AUTOMATION

Although industrial robots have been around for many years, they are still in their infancy. The artificial intelligence robots of science fiction have yet to be developed. However, advancements we expect in the future are limited only by our imagination. Robots are getting smarter. They can "see" using fiber optics and are beginning to process what they see to make program adjustments. They can also use optical or magnetic sensors to locate parts and touch sensors to pick them up without damaging them. Advancements in welding processes will allow greater weld control. Improved and faster computers will allow more complex programming, and improved sensors will give better feedback. The outcome of these advancements will be increased production at lower costs with higher quality.

Summary

The automation of welding does not necessarily have to be in large shops. You may find that in some production applications it would be beneficial to use turntables or positioners. These can either fully or partially automate the welding process so that welder fatigue will be reduced. As you reduce welder fatigue with simple automation equipment, you can increase productivity significantly. Therefore, it is important not to look at automation as a major undertaking in every case. Many welding applications can be improved to increase their speed and reduce weld defects by automating the process.

As the number of companies using automated and robotic equipment has increased, the cost of equipment has significantly decreased and the versatility of the equipment has improved. Some equipment companies provide you with test runs of your product to help you determine the appropriateness of their equipment for your application. Such sample welds will help you determine which equipment is the most cost-effective and appropriate for your application.

Review

1. What were the first industrial robots in America used for?
2. How can CAM technology aid in manufacturing?
3. Why do most robot manufacturers recommend that a skilled welder operate the robot?
4. What must a welder control for a process to be considered manual?
5. List the commonly used manual processes.
6. What must a welder control for a process to be considered semiautomatic?
7. List the commonly used semiautomatic processes.
8. What makes a process a machine process?
9. What makes a process an automatic process?
10. What makes a process an automated process?
11. What types of power provide the industrial robot with movement?
12. In what axes, or directions, can a robot move?
13. What is meant by "teaching" a robot?
14. What is the advantage of storing a robot's program on a disc or CD?

15. Why is it important to reduce restricted areas in a design that will be welded using a robot?

16. Why is it important to make small welds more accurately than large ones?

17. Why must a robot be evaluated for its fitness to work in a welding area?

18. Why is joint tracking important for a robot?

19. Why is it important for a robot to weave the torch?

20. List the safety considerations that must be followed when operating a robotic workstation.

Chapter 30

Other Welding Processes

OBJECTIVES

After completing this chapter, the student should be able to

- describe the various types of SAW fluxes.
- explain how the SAW process works.
- explain how the ESW and EGW processes work.
- name the parts of a SAW setup.
- list the methods of starting the SAW arc.
- list the major advantages and limitations of the SAW, ESW, and EGW processes.
- explain the operating principles for the different special welding processes.
- list the reasons that a particular process should be selected to make a special weld.
- list the operational limitations of each special welding process explained in this chapter.
- explain the thermite welding process for rails.
- describe the characteristics of austenitic manganese steel.
- list the steps required to repair cracks in rails and rail components.
- explain the reason for keeping thermite welding materials dry.

KEY TERMS

bonded fluxes
crucible
electrical resistance
electrogas welding (EGW)
electron beam welding (EBW)
electroslag welding (ESW)
evacuated (vacuum) chamber
flash welding (FW)
fused fluxes
granular fluxing
hardfacing
inertia welding
laser beam welding (LBW)
mechanically mixed fluxes
mold
optical viewing system
percussion welding (PEW)
plasma arc welding (PAW)
resistance welding (RW)
slag pan
strip electrodes
stud welding (SW)
submerged arc welding (SAW)
thermal spraying (THSP)
thermite welding (TW)
ultrasonic welding (USW)
upset welding (UW)

INTRODUCTION

More than 121 different welding and allied processes are listed by the American Welding Society (AWS). This text covers nine of the most commonly used processes that require the welder to have a special skill. This chapter covers 23 additional processes that call for special equipment and techniques. Some of these processes require less skill or knowledge to set up and operate, such as resistance spot welding (RSW). Others demand a great deal of technical information and training, such as **electron beam welding (EBW)**.

The actual operating procedures vary greatly from one manufacturer's machine to another. The specific settings also change from one material to another. Because of these factors, only the general theory, procedures, and applications are discussed in this chapter. More information can be obtained from the AWS or directly from the manufacturer of the equipment being operated. The skill needed to operate this equipment can be learned on the job or in classes taught by the specific equipment manufacturer.

CONSTANT CURRENT WELDING PROCESSES

In addition to the two constant potential (CP) welding processes GMAW and FCAW that are covered in other chapters, three other CP processes are covered in this chapter. These processes are **submerged arc welding (SAW)**, **electroslag welding (ESW)**, and **electrogas welding (EGW)**. Each of these three processes provides the welding industry with significant specialized benefits.

SAW, ESW, and EGW can be considered the workhorses of the fabrication industry. These processes are used to fabricate large, thick sections. They can weld metal ranging from 3/8 in. (10 mm) to more than 20 in. (508 mm) thick in a single operation, depending on the process selected. They are also used to cover large areas on tanks and pressure vessels with welded overlay of a special alloy. This allows the unit to be fabricated out of a less expensive metal but to have the surface of the expensive alloy. The total cost of the fabrication is less, yet it will provide the same or better service.

Submerged Arc Welding (SAW)

The early 1930s saw the introduction of the submerged arc welding (SAW) process. The first of many processes to use a continuous wire as the electrode, its acceptance accelerated during World War II. The yearly tonnage of SAW electrode wire used has increased each year as more automation and robotic welding is introduced to new applications.

Submerged arc welding (SAW) is a fusion welding process in which the heat is produced from an arc between the work and a continuously fed filler metal electrode. The molten weld pool is protected from the surrounding atmosphere by a thick blanket of molten flux and slag formed from the **granular fluxing** material preplaced on the work, **Figure 30-1**. **Figure 30-2** shows an application of the SAW process.

Weld Travel Movement along a joint can be provided manually or mechanically. Handheld travel can be a welder manually moving the gun at a constant speed along the

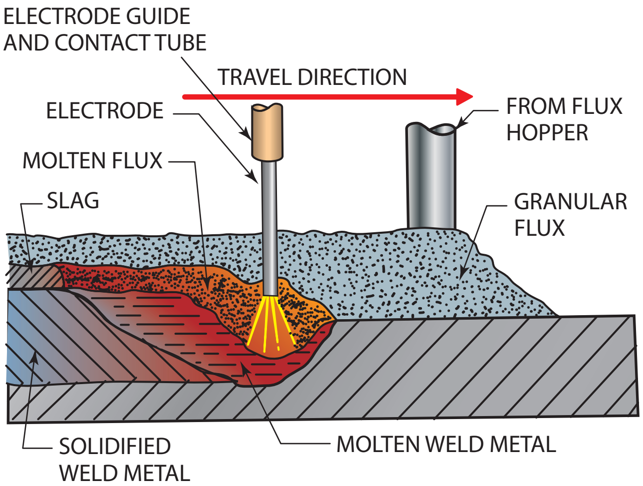


FIGURE 30-1 Submerged arc welding (SAW).

Courtesy of Licoln Electric Company

FIGURE 30-2 Automated submerged arc welding provides high-quality weld depositions.

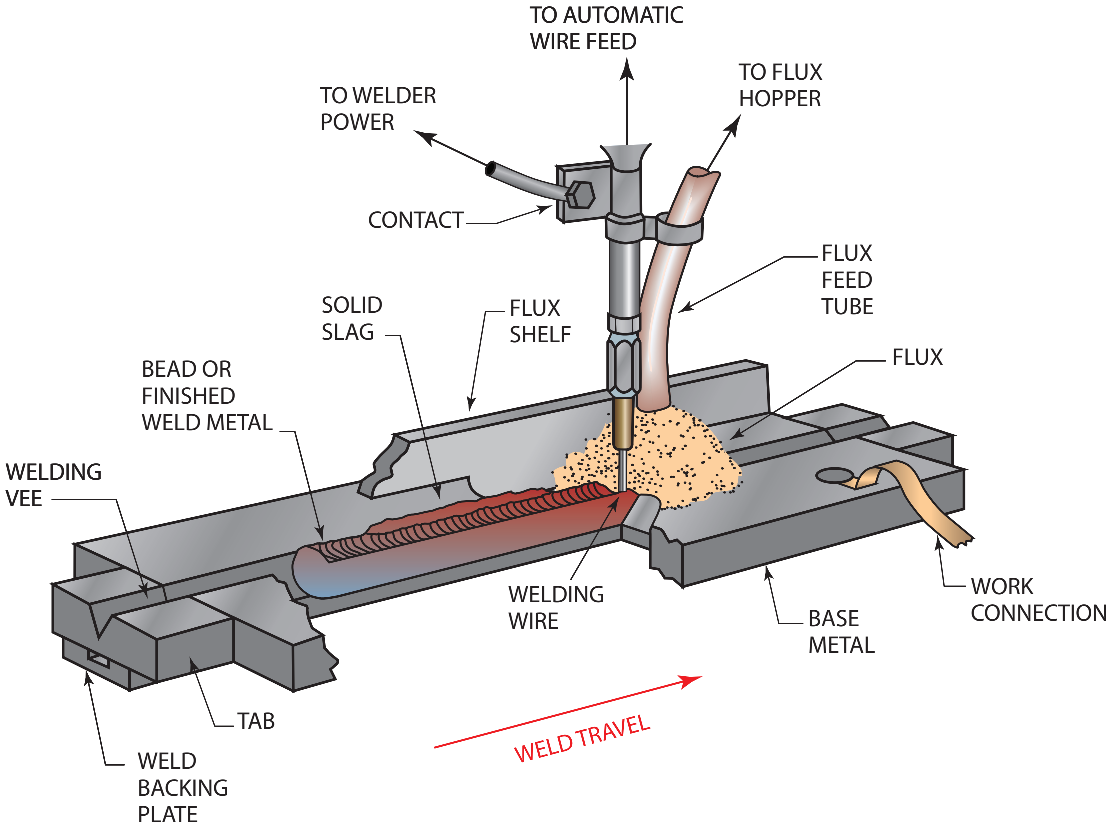


FIGURE 30-3 Schematic of a SAW setup in which the work is moved past the welding gun.

joint, or there might be a small gun-mounted motor and friction drive wheel to provide a more consistent travel rate.

Mechanical travel can be provided by either moving the gun along the joint or moving the work past a fixed gun. Gun travel can be as simple as using a portable tractor-type carriage, **Figure 30-3**, or as complex as a robotic arm. Work travel can be provided using rollers or other types of positioners. In some cases, a positioner may be used in unison with some type of gun travel. These systems lend themselves to computer-controlled automation.

THINK GREEN

Reduce Air Pollution

The SA welding process releases very little welding fumes into the atmosphere because the arc is completely covered with a heavy layer of granular flux.

Electrode SAW filler metals are available as standard wire and in several special forms. The wire comes in sizes from 1/16 in. to 1/4 in. (1.6 mm to 6 mm). Some filler metal is supplied as twisted wire. It is used to give the arc some oscillating movement as the wire enters the weld, **Figure 30-4**. This oscillation helps fuse the toe of the weld to the base metal. **Strip electrodes** are thin, flat ribbons of filler metal that are used for surfacing applications. The strips are available up to 3 in. (76 mm) wide and in several thicknesses.

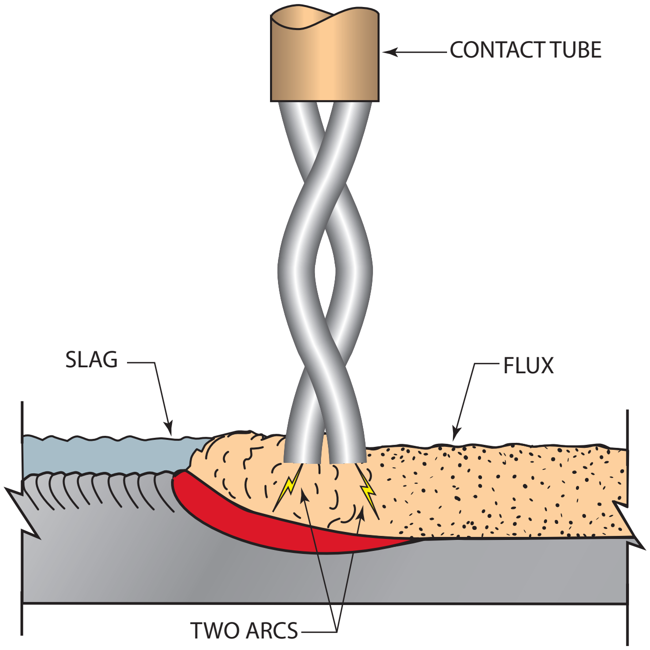


FIGURE 30-4 Twisted SAW filler wire.

Electrode Classification Electrode classifications are prefixed with the letter *E*, designating an electrode, **Figure 30-5**. The next letter, *L* (low), *M* (medium), or *H* (high), refers to the range of manganese. The next one or two digits indicate the normal carbon point of the wire. One carbon

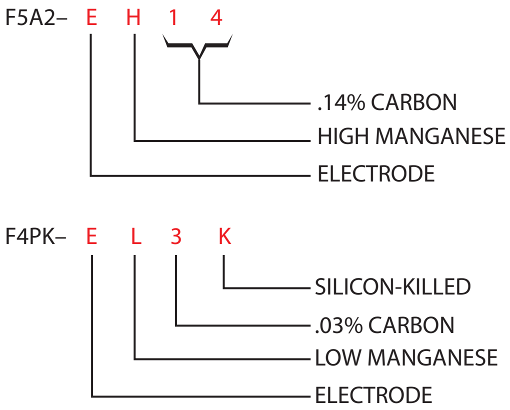


FIGURE 30-5 AWS filler wire identification system.

point equals 0.01% carbon. The last letter is *K* and may or may not be used. When it is used, it means the electrode was drawn from a silicon-killed, deoxidized steel.

Flux

Fluxes are classified according to the mechanical properties of the weld metal deposited. The same chemically composed flux can have many different classifications, depending on the classification of the electrode it is used with and the condition of heat treatment given the weld for testing.

Flux Classification The basic flux classification is prefixed with the letter *F*, which designates it as a flux, **Figure 30-6**. This is followed by one digit, which represents 10,000 psi (69 MPa) minimum tensile strength of the weld. The digit is followed by the letter *A* or *P*. The *A* means the weld was tested and classified in the "as-welded condition." The *P* means the weld was tested and classified after the prescribed amount of postweld heat treatment. The next item in the classification is a single digit or the letter *Z*. The digit indicates the lowest temperature in divisions of 10°F, starting at 0°F units, that the weld metal will meet or exceed the required 20

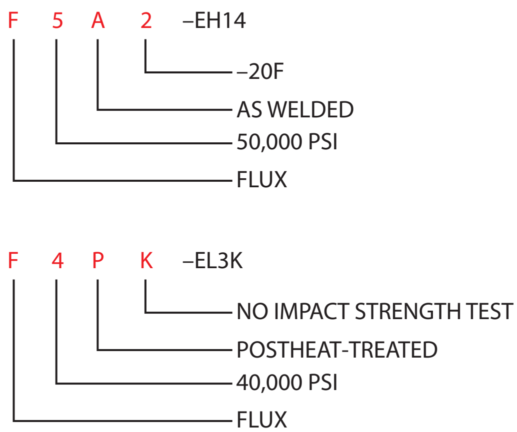


FIGURE 30-6 AWS flux identification system.

foot-pound (27 J) impact strength test. For example, in the flux identified as **F 5 A "1" − xxxx**, the "1" is −10°F (−23°C), and in the flux identified as **F 5 A "3" − xxxx**, the "3" is −30°F (−34°C). The letter *Z* indicates that no impact strength test is required.

Flux Types Fluxes are grouped into three types according to their method of manufacture. These types are fused, bonded, and mechanically mixed. Granulated fluxes are available in bags or bulk containers.

Fused Fluxes **Fused fluxes** are mixtures that have been heated until they melt into a solid metallic glass. They are then cooled and ground into the desired granular size range. Fused fluxes cannot be alloyed because they are a form of glass and all components in that glass are essentially oxides. They will not dissolve metals without reacting with them, thereby reducing their effectiveness as alloying materials.

THINK GREEN

Recycle SA Welding Flux

A vacuum system can be used to follow along behind the welding gun to recover the unfused flux. This flux can be easily screened to remove any debris and reused.

Bonded Fluxes **Bonded fluxes** are a mixture of fine particles of fluxing agents, deoxidizers, alloying elements, metal compounds, and a suitable binder that holds the mixture together in small, hard granules. Each granule is composed of all the ingredients in the correct proportions.

Mechanically Mixed Fluxes **Mechanically mixed fluxes** are mixtures of fused and bonded fluxes or a fine mixture of agents in a desired proportion for a certain job.

Flux Storage To prevent contamination of the weld by hydrogen, the flux must be kept dry and free from oils or other hydrocarbons. If flux becomes damp, then it must be re-dried. Excessive levels of hydrogen in some steels can cause porosity. In hardenable steels, even small amounts of hydrogen can cause underbead cracking. Commercially available dryers are the best method of drying flux. Do not dry flux by using a direct flame. This may fuse the flux together; at the same time, the flame produces water vapor that might condense on the flux.

Advantages of SAW

The growth in the use of SAW has been due to its major advantages:

- Minimum operator protection required—The heavy blanket of granular flux covers all of the arc light except for an occasional flash. The absence of the arc light means that many welders can work close to each other without the problem of arc flash. The

welder does not have to wear a welding helmet, so visibility and safety are improved. The granular flux also prevents most of the welding smoke from escaping. Even with a large number of welders operating in confined spaces, forced ventilation is virtually eliminated. The heating and cooling costs of the shop are lessened because the amount of ventilation required is greatly reduced.

- Highest deposition rate—Using large-diameter wires, more than 40 lb/hr (18 kg/hr) can be deposited. This rate is nearly two-times the rate of FCAW and four-times that of SMAW. No process other than electroslag welding can come close to this deposition rate.
- Efficient use of materials—With SAW, there is no spatter which is a waste of filler metal, and it causes postweld cleanup problems. All of the electrode is transferred and becomes weld deposit. Only the melted flux needed for the weld is lost. Unfused granular flux can be retrieved and reused. The amount of flux consumed can be controlled by varying the arc length, which is done by changing the arc voltage.
- Weld size—Flat groove or fillet welds as large as 1 in. (25 mm) can be made in one pass using a single electrode. Larger sizes are possible with multiple electrodes.
- Easily adapted—With this process, the flux and wire are purchased separately. The flux can be used to change the alloys in the weld metal deposited from the electrode. By changing the flux, the properties of the weld are altered. The composition of the flux is easily changed to meet specific metallurgical properties. Two or more fluxes can be mixed, or granulated metal can be added to a flux or mixture to meet individual needs.
- High-quality welds—Many codes permit SAW to be used on structural iron, pressure vessels, cryogenic cylinders, and in many other critical applications.

Disadvantages of SAW

As with other processes, the submerged arc processes have several disadvantages:

- Restricted to flat position and horizontal fillets—Because the fluxes needed for submerged arc welding flow easily, welding is restricted to those positions in which the flux can produce a self-supporting blanket.
- Welding parameters need careful control—Because the flux hides the weld pool, welding conditions must be preset on the basis of experiments or with proven tabular information, including the contact tip-to-work distance, the current, the travel speed, and the voltage. Arc voltage must be carefully controlled to ensure the proper weld profile. Equally important, deviations in arc voltage can cause significant changes in the weld composition when using the fluxes as the source of alloys.
- Mechanical guidance is necessary—Without some sort of guidance, the arc could easily move away from the joint being welded. To take advantage of the deep penetration possible with the process, accurate positioning is very important. This need can become an expensive complication with other than perfectly straight joints. Even with good guidance systems, positioning problems can develop if the wire does not have a large and uniform cast (or little bend) and a negligible helix (twist). Significant variations in cast or a large helix will cause the arc to wander. This is particularly important when a long wire electrode extension is used to increase deposition rates.

HANDHELD SAW

Handheld SA welding is increasing in usage for a variety of reasons. One of the most significant is that there are little if any fumes or smoke to exhaust. New local, state, and federal laws have put restrictions on the material that can be free-vented into the atmosphere. There are requirements in some locations that require the welding shop ventilation systems to have collectors and filtration equipment in operation. This process does not eliminate all fumes and smoke, but the reduction can significantly reduce the shop's ventilation costs. A shop using SA welding is a much cleaner place to work.

The arc light and spatter are blanketed by the flux covering so the welding technicians can wear lighter protective clothing. This reduces welder fatigue and increases productivity, **Figure 30-7**.

ELECTROSLAG WELDING (ESW)

Electroslag welding (ESW) is not an arc welding process because no arc is produced below the molten flux surface. The heat for welding is produced as a result of the electrical resistance of the molten flux. Fluxes used for electroslag welding produce slags during the weld that have special

Courtesy of Licoln Electric Company

FIGURE 30-7 Handheld SA welding gun.

characteristics. The slags are designed to be so highly conductive in the molten state that they can replace the arc without interrupting the electrical circuit. These slags are very fluid, and they must be relatively deep to maintain control of the circuit. Because the slags are fluid, some type of dam must be used to contain them.

The wire or wires are fed into the cavity and guided by contact tips using equipment similar to that used with the submerged arc process. The need for a controlled pool size and the use of contact tip or tips within the cavity mean that only relatively heavy plate can be welded with this process.

Heated by its own resistance to the flow of current, the flux temperature is raised well above that of the plate to be welded, generally above 3200°F (1760°C). That heat is used to prefuse the plate, which melts at temperatures below 2790°F (1532°C), so the metal being cast into it can bond with the plate edges. The flux also serves as a lubricant between the solidified metal and the dams. Additional flux must be added to the cavity to compensate for those losses. The wire is heated to its melting temperature by its internal resistance and remains fluid as it drops through the superheated flux to the molten weld pool.

The welding process is initiated by striking an arc between the wire and a bottom plate. After the arc energy melts enough flux to produce a pool of conductive slag, the arc is extinguished by increasing the distance between the wire tip and plate or by reducing the voltage from the power supply. One drawback of the process is that the metal produced during the starting process is defective and must be removed and repaired manually. This procedure must be followed at any position where welding has been interrupted and restarted.

Water-cooled copper dams confine the molten slag, **Figure 30-8**. The copper dams may extend the full length of the joint, or smaller dams may be moved up the joint as the weld metal solidifies. The rate of movement must match the speed at which the electrodes and the base metal are melted. The vertical progression is controlled automatically by sensing voltage changes with constant current power supplies or by sensing current with constant-voltage power supplies. The dams and the base metal plates serve as a cooling medium. The lower part of the metal bath solidifies progressively in an upward direction. Slag is added by the operator as needed.

Electroslag welding is suitable for welding joints in thick metal plates because the large molten weld pool is confined and molded by the dams. The joint is welded in one pass.

Electroslag welding tends to produce a large grain size for two reasons: (1) the large mass of metal that is molten at a given time and (2) the slow cooling of the metal.

Advantages

The electroslag welding process has the following advantages:

- Minimum joint preparation.
- Welds can be made with a thickness of several feet (meters) in plain and alloy steels using multiple electrodes.
- High welding speed.
- Minimum distortion.
- The weld metal is highly purified by the metallurgical slag.

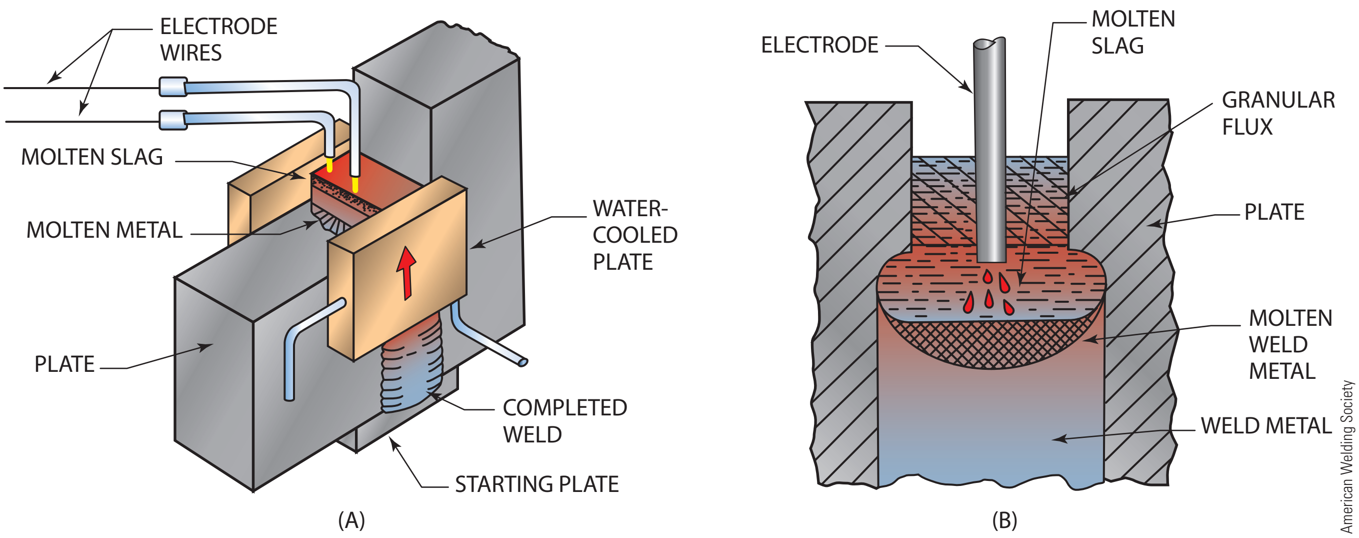


FIGURE 30-8 Diagram of electroslag welding process: (A) section through workpieces and (B) weld during the making of the weld.

Disadvantages

The electroslag welding process has the following disadvantages:

- Massive, expensive welding equipment and guidance systems are required.
- Lengthy setup times are needed.
- It cannot be used for welding the most commonly used thicknesses of plate.
- It can be used for only vertically positioned joints.
- It produces welds with very pronounced columnar microstructures and poor toughness.

ELECTROGAS WELDING (EGW)

Electrogas welding (EGW) is similar to electroslag welding in a number of ways. In addition to the power supply and wire feed, both processes are welded in the vertical up position using dams to contain the molten weld pool. Both processes can be used to weld on thick sections; however, EGW can weld plates as thin as 3/8 in. (10 mm).

The major difference in these processes is that there is an arc between the electrode and the molten weld pool with EGW. The molten weld pool is protected from the atmosphere by a shielding gas or by a flux core in the filler electrode, **Figure 30-9A** and **B**.

When a shielding gas is used, a mixture of carbon dioxide (CO_2) and argon (Ar) works well. The shielding gas flows through holes in the copper dam to cover the molten weld pool.

There are two parts to the identification system—one for the solid wire and the other for the tubular, flux-filled electrodes.

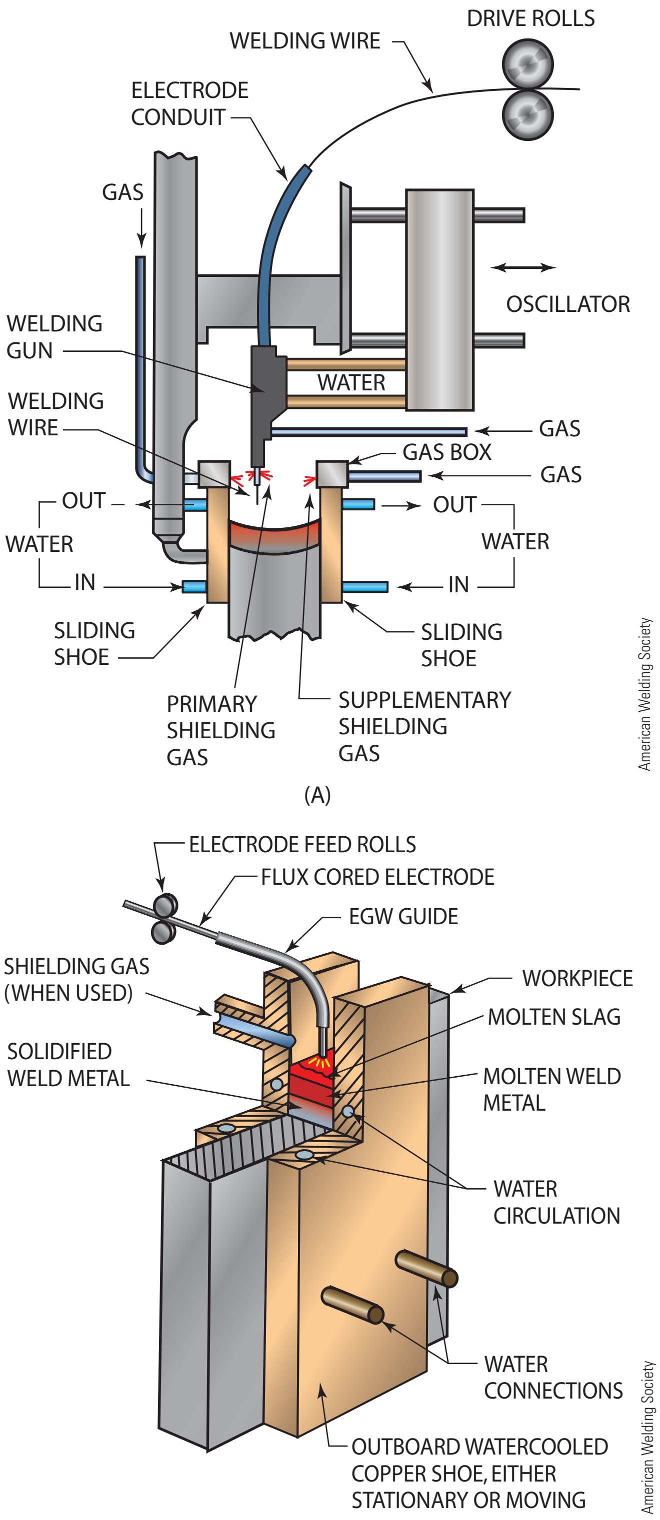


FIGURE 30-9 (A) Electrogas welding with a solid wire electrode. (B) Electrogas welding with a self-shielded flux cored electrode.

RESISTANCE WELDING

Resistance welding (RW) is a process in which fusion between the parts' surfaces occurs as a result of the heat produced by the electric resistance between the parts' contacting surfaces. The welding current required to make a resistance weld must be at a very low voltage but at a high amperage. Pressure is constantly applied while the current is applied to ensure a continuous electrical circuit and to forge the heated parts together. Heat is developed in the assembly to be welded, and pressure is applied by the welding machine through the electrodes. During the welding cycle, the mating surfaces of the parts are heated to a plastic state just before melting and are forced together. The surfaces do not have to melt for a weld to occur. The parts are usually joined as a result of heat and pressure and not their being melted together. Fluxes or filler metals are not needed for this welding process. The heat produced in the weld may be expressed in the following formula:

$H = I^2R$ where H = Heat
I^2 = Welding current squared
R = Resistance

The current for resistance welding is usually supplied by either a transformer or a transformer/capacitor arrangement. The transformer, in both power supplies, is used to convert the high line voltage (low-amperage)

power to the welding high-amperage current at a low voltage. A capacitor, when used, stores the welding current until it is used. This storage capacity allows such machines to use a smaller-size transformer. The required pressure, or electrode force, is applied to the workpiece by pneumatic, hydraulic, or mechanical means. The pressure applied may be as little as a few ounces (grams) for very small welders to tens of thousands of pounds (kilos) for large spot welders.

Most resistance welding machines consist of the following three components:

- The mechanical system to hold the workpiece and to apply the electrode force
- The electrical circuit made up of a transformer and, if needed, a capacitor, a current regulator, and a secondary circuit to conduct the welding current to the workpiece
- The control system to regulate the time of the welding cycle

There are several basic resistance welding processes. These processes include spot (RSW), seam (RSEW), high-frequency seam (RSEW-HF), projection (PW), flash (FW), upset (UW), and percussion (PEW) welding.

Resistance welding is one of the most useful and practical methods of joining metal. This process is ideally suited to high-production methods.

Resistance Spot Welding (RSW)

Spot welding is the most common of the various resistance welding processes. In this process, the weld is produced by the heat obtained at the interface between the workpieces. This heat is due to the resistance to the flow of electric current through the workpieces, which are held together by pressure from the electrode, **Figure 30-10**. The size and shape of the formed welds are controlled somewhat by the size and contour of the electrodes.

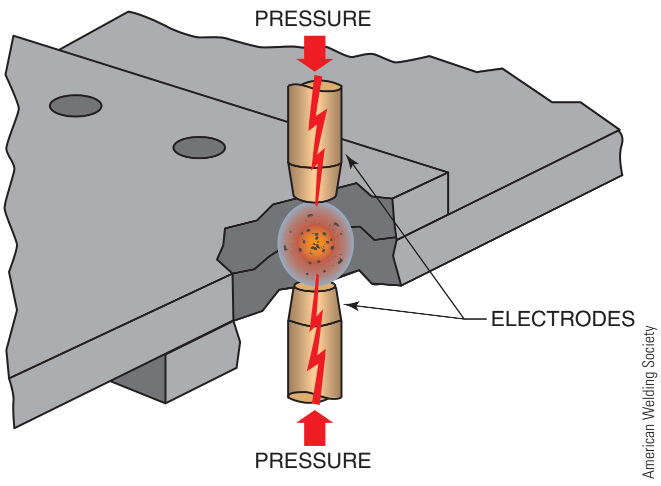


FIGURE 30-10 Heat resulting from resistance of the current through the metal held under pressure by the electrodes creates fusion of the two workpieces during spot welding.

The welding time is controlled by a timer built into the machine or by a computer program. The timer controls four different steps, **Figure 30-11**. The steps are as follows:

- Squeeze time, or the time between the first application of electrode force and the first application of welding current
- Weld time, or the actual time the current flows
- Hold time, or the period during which the electrode force is applied and the welding current is shut off
- Off period, or the time during which the electrodes are not contacting the workpieces

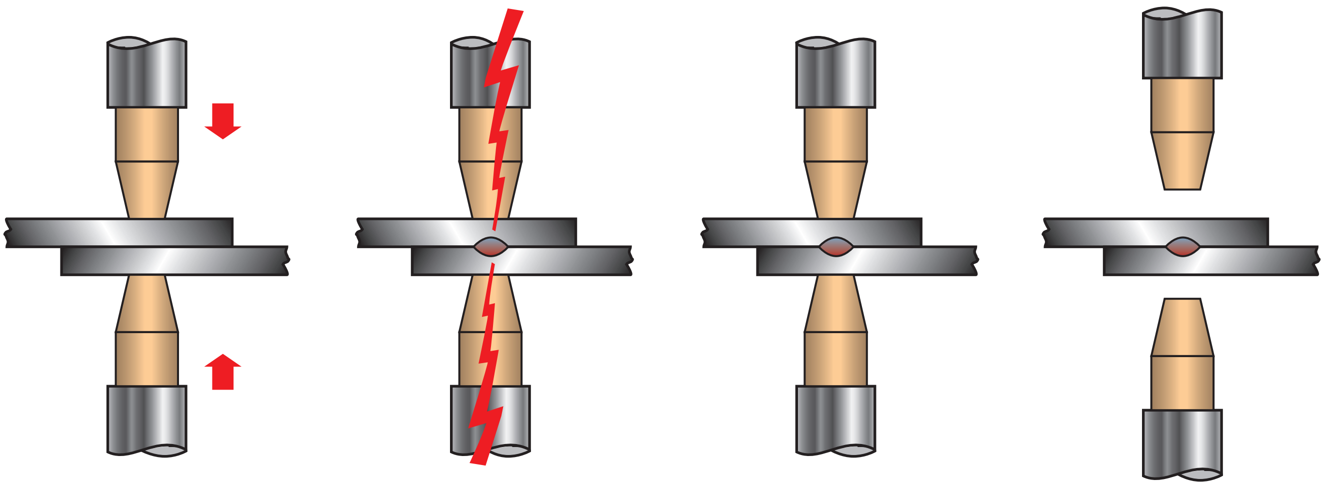


FIGURE 30-11 Basic periods of spot welding.

Tables supplied by the machine manufacturer provide information for the exact time for each stage for different types and thicknesses of metal.

Material from 0.001 in. (0.025 mm) to 1 in. (25 mm) thick may be joined by spot welding.

Spot Welding Machines

The three types of spot welding machines commonly used are rocker arm, press type, and portable type.

In rocker-arm spot welders, the lower electrode is stationary while movement is transferred to the upper electrode by means of an arm, which moves about a pivot point. The rocker arm can be moved by one of three methods: foot pedal, air or hydraulic cylinder, or electric motor. Rocker-arm welders, **Figure 30-12**, are available with throat depths from 12 in. to 48 in. (30 cm to 122 cm) and transformer capacities from 10 kVA to 20 kVA. The abbreviation kVA stands for kilovolt amps and is roughly equivalent to watts. Both kVA and watts are power measurements.

In press-type spot welders the movement of the upper electrode is controlled by a pneumatic or hydraulic cylinder. This type of welder is used for welding heavy sections. Throats with a depth of 60 in. (152 cm) are available with capacities up to 500 kVA.

Portable spot welders are used where work is too large to be moved. These machines are complete with a pressure cylinder, transformers, electrode holders, electrodes, and the necessary controls.

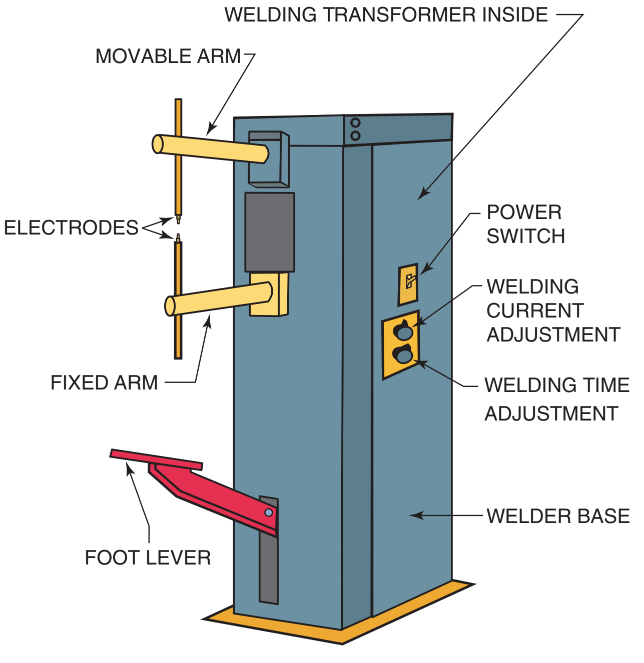


FIGURE 30-12 Rocker-arm spot welder operates by depressing the foot switch, which brings the tongs onto the work and the weld cycle steps through a preset time adjustment.

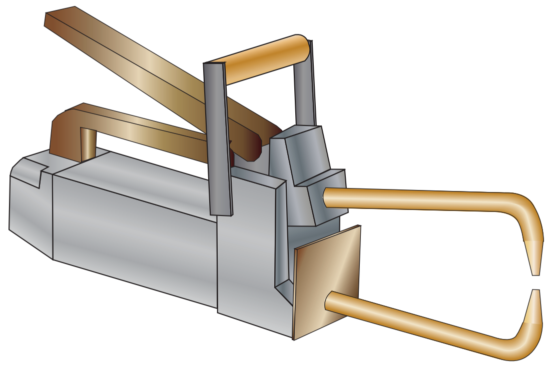


FIGURE 30-13 Small welder for fine, detailed work.

Portable spot welders are used in the mass production of automobiles, aircraft, railroad cars, home appliances, and similar products where relatively thin sheets are to be welded, **Figure 30-13**.

Multiple-Spot Welders

Multiple-spot welders are used when a high production rate is a requirement. The multiple-spot welder shown in **Figure 30-14** is specially designed for auto body panels. Some welds can make as many as 20 or more welds at one time. Most multiple-spot welders have a series of air-operated or hydraulically operated guns mounted on a header and use a common bar for the lower electrode. The welding guns are connected by flexible wires to individual transformers or to a common bus bar attached to the transformer, **Figure 30-15**.

All guns make contact with the workpiece at the same time. They can be fired either in a certain sequence or all at the same time. These types of welders are widely used in the automobile industry.

Seam Welding (RSEW)

Seam welding is similar in some ways to spot welding except that the spots are spaced so closely together that they actually overlap one another to make a continuous seam weld.

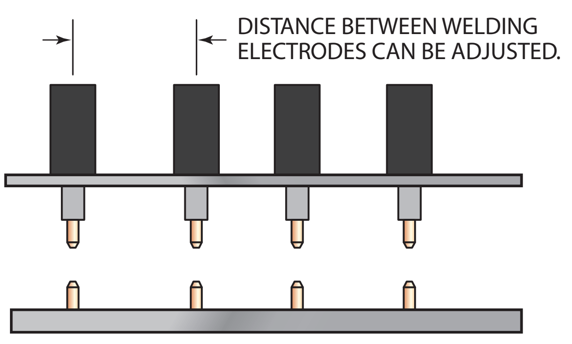


FIGURE 30-14 Multiple-spot welder, which is a special welder designed as an auto instrument panel welder.

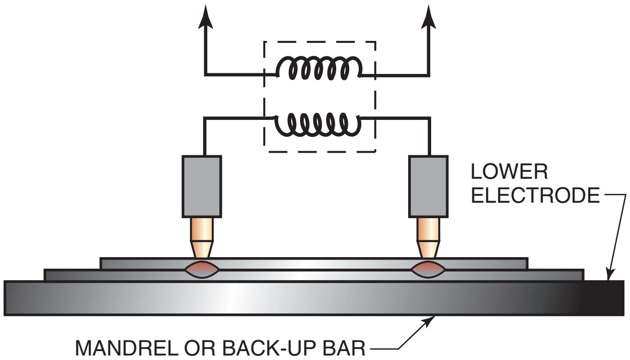


FIGURE 30-15 The arrangement of electrodes in multiple-spot welding.

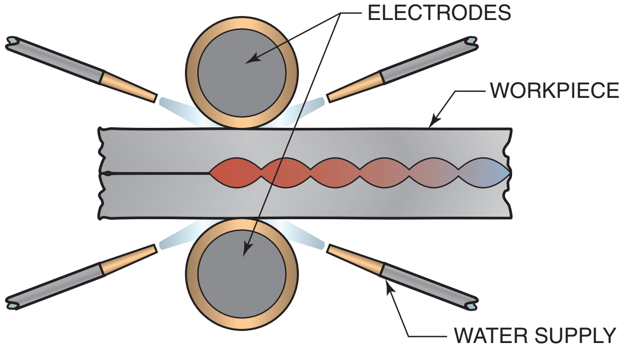


FIGURE 30-17 Schematic illustration of the seam welding process.

Seam welding is accomplished by using roller-type electrodes in the form of wheels that are 6 in. (152 mm) to 9 in. (229 mm) or more in diameter, **Figure 30-16**. These roller-type electrodes are usually copper alloy discs 3/8 in. (10 mm) to 5/8 in. (16 mm) thick. Cooling is achieved by a constant stream of water directed to the electrode near the weld, **Figure 30-17**.

Welding is done either with the roller electrodes in motion or while they are stopped for an instant. If continuous motion is used, then the rate of welding usually varies between 1 ft and 5 ft (30 cm to 152 cm) per minute. The greatest welding speed is obtained on the thinnest materials. An indexing mechanism can be used when the wheels are to be stopped for each weld.

Electric timing equipment is useful when it is necessary to provide the precise control required for the highest-quality welds. Spot welds can be positioned at almost any interval desired by simply adjusting the timing and rate of electrode motion.

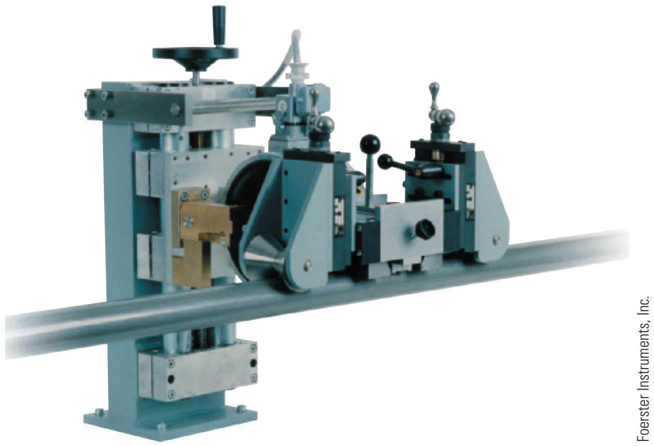


FIGURE 30-18 Tweezer-type seam welder with automatic cycling for circular flat pack.

It is possible to change the welding current and electrode pressure to control the surface condition and width of the weld. The seam width should be approximately two-times the thickness of the sheet plus 1/16 in. (2 mm). **Figure 30-18** shows a tweezer-type seam welder with automatic cycling.

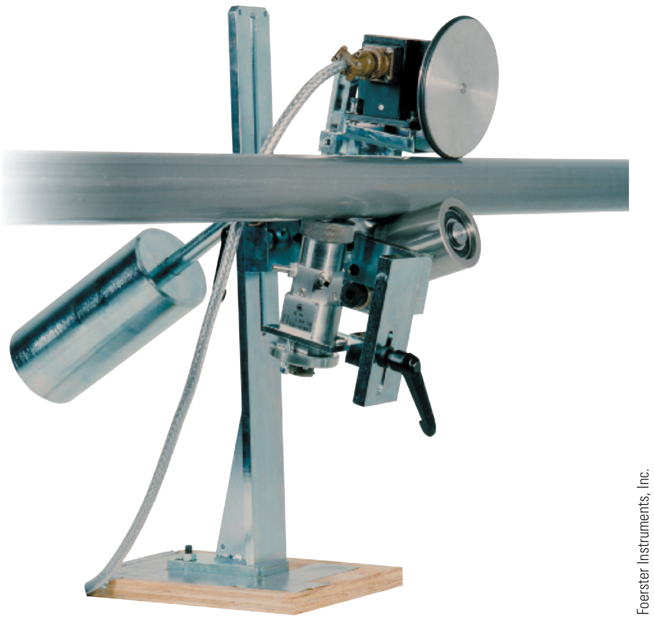


FIGURE 30-16 Seam welder.

Types of Resistance Seam Welds

Figure 30-19 illustrates the type of seams used in most seam welding processes. The lap seam is the most common of these seams. The tops and bottoms of containers

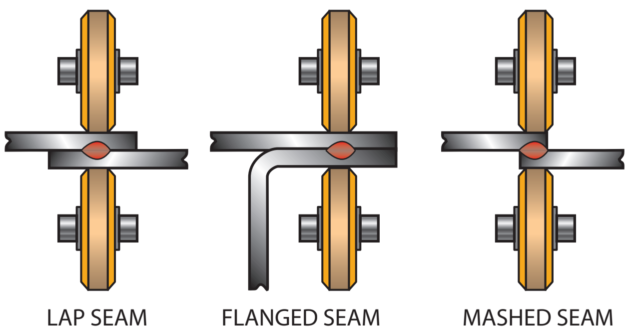


FIGURE 30-19 Types of seam welds.

are usually fastened together with a flanged seam. For a metal thickness of 1/16 in. (2 mm), the mash seam is often used. The electrode face should be wide enough to cover the overlap by approximately one and one-half times the thickness of the sheet.

High-Frequency Resistance Seam Welding (RSEW-HF) This process is similar to RSEW in some ways. The major differences are that the welding current is supplied as high-frequency, 200 to 500 kHz as opposed to DC or 60-cycle AC. The high-frequency power provides very localized heating. This heating is a result of the resistance to the current induced in the metal and not to the resistance between parts. As a consequence of this localized heating, pipe and tubing can be welded with little loss of power flowing around the back side of the joint.

RSEW-HF is used in the production of welded pipe, tubing, and structural shapes. It works very well for the fabrication of I-beams, H-beams, channels, and so on. These welded structural shapes are lighter and stronger than their roll-formed counterparts.

Resistance Projection Welding (RPW) Projection welding is somewhat similar to spot welding in that it involves joining parts by a resistance welding process.

To make a projection weld, projections are formed on at least one of the workpieces at the points where welds are desired. The projections—small, raised areas—can be any shape, such as round, oval, circular, oblong, or diamond. They can be formed by embossing, casting, stamping, or machining.

The workpieces that have the projections and the other workpiece are placed between plain, large-area electrodes in the welding machine, **Figure 30-20**. Pressure is applied and then the welding current is turned on. Because nearly all of the resistance is in the projections, most of the heating occurs at the points where welds are desired. The heat causes the projections and the opposing metal to soften. The pressure from the electrodes causes the softened projections to flatten, resulting in fusion of the workpieces.

With this type of welding, a complicated electrode shape is not required. In cases where the weld area does not have a regular shape, the electrode can be shaped to fit the surface.

There are many variables in this type of welding. Some of these variables are thickness of metal, number of projections, and kind of material. These variables make it difficult to predetermine the current and electrode pressure required.

Steel plate, galvanized sheet steel, and stainless steels can be joined using projection welding.

Flash Welding **Flash welding (FW)** may be considered a resistance welding process. Fusion is produced over the ends of stock by heat produced from the resistance to the flow of electric current between the two surfaces. Pressure is applied after heating is completed. As a result, the material is forced together and fusion takes place. The basic steps in flash welding are as follows:

1. Clamp the parts together in dies (these dies conduct the electric current to the workpieces).
2. Move one part toward the other part until an arc is established.
3. When the ends of the parts reach a plastic temperature, pressure is applied, causing the softened end surfaces to be fused together and deformed. This deformation is referred to as upset.
4. Cut off the welding current when fusion and upset are complete, **Figure 30-21**.

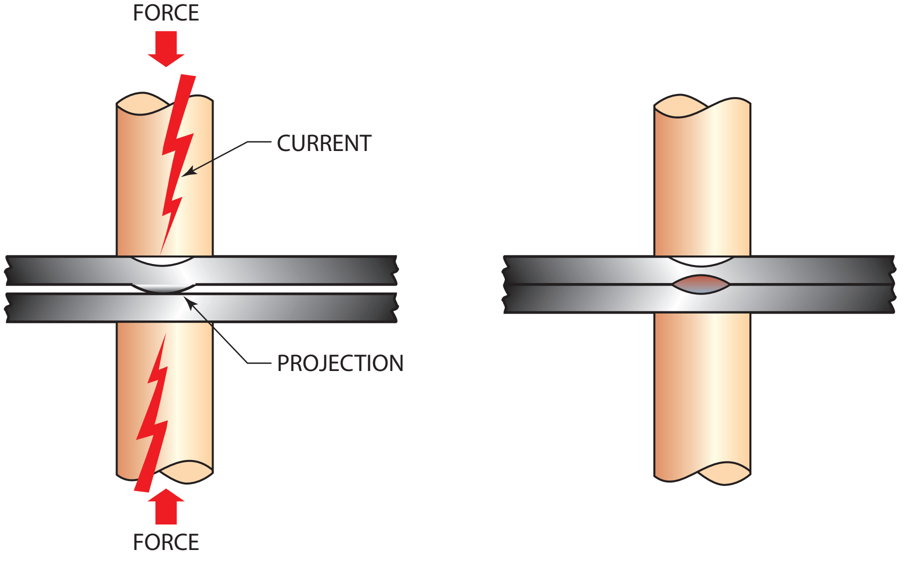


FIGURE 30-20 Projection welding.

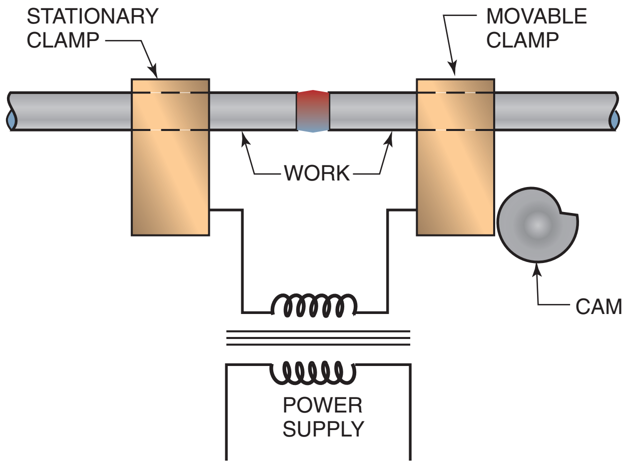


FIGURE 30-21 Schematic diagram of the flash welding process.

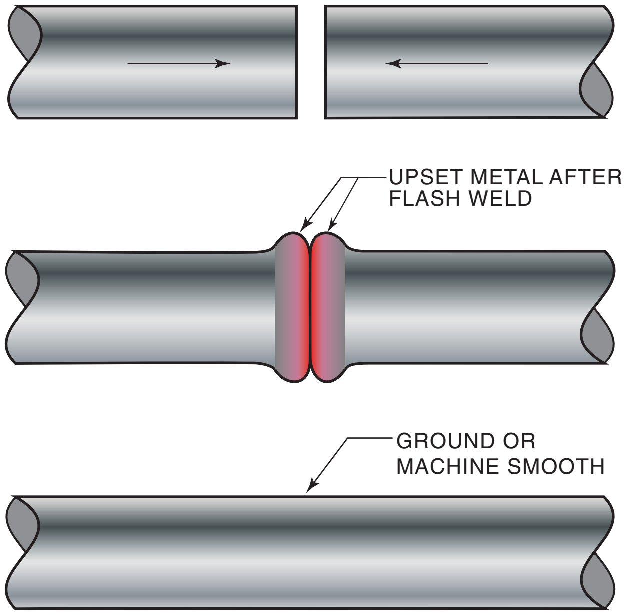


FIGURE 30-22 The weld flash is trimmed off after an upset weld.

Flash welding may be used to join dissimilar aluminum alloys and to join aluminum to other metals. Flash welding is a high-volume production process. Unless a large number of pieces are to be welded, it is very costly to prepare the work-holding dies. The time and materials involved in setting up the job are also cost factors. The production rate is high because the welding time is short.

Upset Welding (UW) Welding small areas is usually done by the **upset welding (UW)** method. In this form of welding, two pieces of metal with the same cross-section are gripped and pressed together. Heat is generated in the contact surfaces by **electrical resistance**. The upset at the interface extrudes the contaminated contact area to the outside, where it is trimmed, **Figure 30-22**.

Flash welding has an arcing action at the contacting surfaces. No flashing occurs in the upset process. The main difference between the upset and flash processes is that less current is needed in the upset process and welding time is extended.

Percussion Welding **Percussion welding (PEW)** is a resistance welding process and is actually a variation of flash welding. Fusion is obtained simultaneously over the entire area of the contacting surfaces. The heat that causes fusion is obtained from an electric arc produced by the rapid discharge of stored energy. Immediately after or during the electrical discharge, impact pressure is applied by a hammer blow or by the snap releasing of a spring, **Figure 30-23**. A percussion weld is similar to a flash weld. A short application of high-intensity energy instantly heats the surfaces to be joined. This rapid heating is almost immediately followed by a quick blow to make the weld.

The action of this process is very rapid. There is little heating effect on the metal adjacent to the weld. Thus, it is possible for heat-treated parts to be welded without becoming annealed. Examples of this type of welding include welding copper to aluminum or stainless steel, and adding Stellite tips to tools, silver contact tips to copper, cast iron to steel, and zinc to steel.

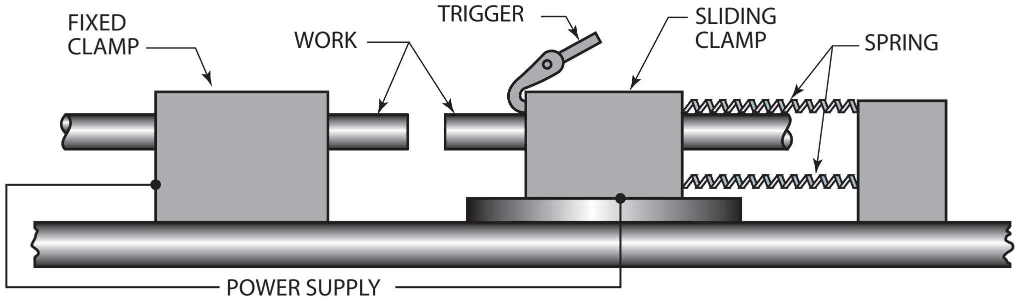


FIGURE 30-23 Principle of percussion welding.

ELECTRON BEAM WELDING (EBW)

Electron beam welding is used in the auto, electronics, pipeline, shipbuilding, aerospace, and high-speed welded tubing industries. Temperatures up to 180,000°F (100,000°C) are generated by electron beam welding machines. At such high temperatures, the machine can accurately vaporize metals and ceramics. Deep, strong welds with no heat deformation are produced between close-fitting parts. The welds have high strength and purity. This process can be used to join dissimilar metals.

Electron beam welding utilizes the energy from a fast-moving beam of electrons focused on the base material. The electrons strike the metal surface, giving up their kinetic energy almost completely in the form of heat. Welds are made in a vacuum (10^{-3} mm Hg to 10^{-5} mm Hg), which practically eliminates contamination of the weld material by the gases left in the vacuum chamber. The high vacuum is necessary to produce and focus a stable, uniform electron beam. Welds produced by this process are coalesced from vacuum-melted material, which eliminates the usual fusion weld contaminants caused by water vapor, oxygen, nitrogen, hydrogen, and slag.

Early electron beam welders needed hard vacuums for both the beam and welding chambers. New units need only a soft vacuum in the welding chamber (attained in only a few seconds) or, in the case of some new units, welds can be made 1/4 in. (6 mm) outside the **evacuated (vacuum) chamber**. Nonvacuum welding is thought of as a supplement to, not as a replacement for, conventional EB welding.

Electron Beam Welding Gun

The electron gun consists of a filament, a cathode, an anode, and a focusing coil. These parts are mounted above the work chamber, as shown in **Figure 30-24**. The electrons from the heated filament carry a negative charge and are emitted by the cathode and attracted by the anode. The anode has an opening through which the electrons pass.

The electrons then move through a magnetic field, which is produced by an electromagnetic focusing coil. The machine is equipped with an **optical viewing system**, **Figure 30-25**. This system provides a line of sight down the path of the electron beam centerline to the weld area when the beam is off, **Figure 30-26**.

It is possible to vary the current to the focusing coil so that the operator can focus the beam from a sharp focus to a beam 1/4 in. (6 mm) in diameter. Focal points above, on, or below the work surface are provided to modify the weld pattern.

Electron Beam Seam Tracking

Electron beam equipment is designed and manufactured so that the worktable can be rotated beneath the gun for circular welds or driven along a path that corresponds to, or is parallel to, the centerline of the chamber for linear welds. Sometimes the gun itself is moved.

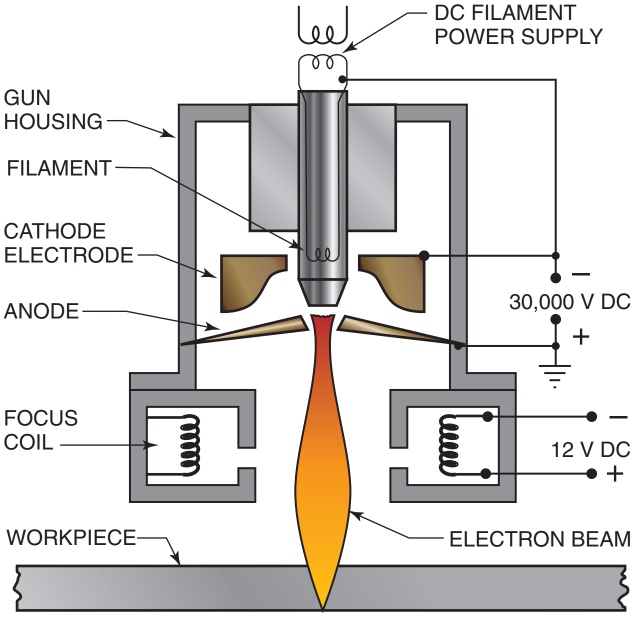


FIGURE 30-24 Electron beam gun produces an accurately controlled heat source adjustable for length and point of focus.

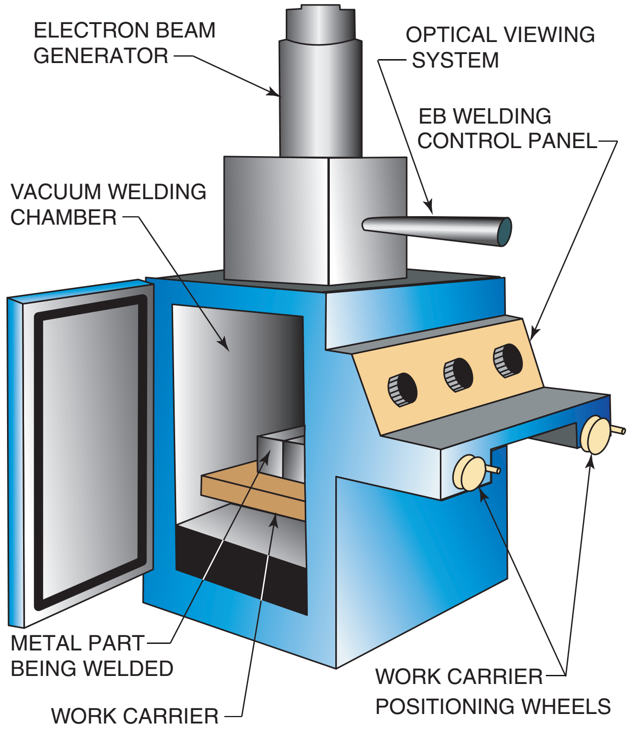


FIGURE 30-25 7.5-kW electron beam welder.

Automatic seam tracking is available to track any seam. The amount of misalignment of the placement of the joint may be a few thousandths of an inch or a few inches. The seam tracking device continuously checks the actual

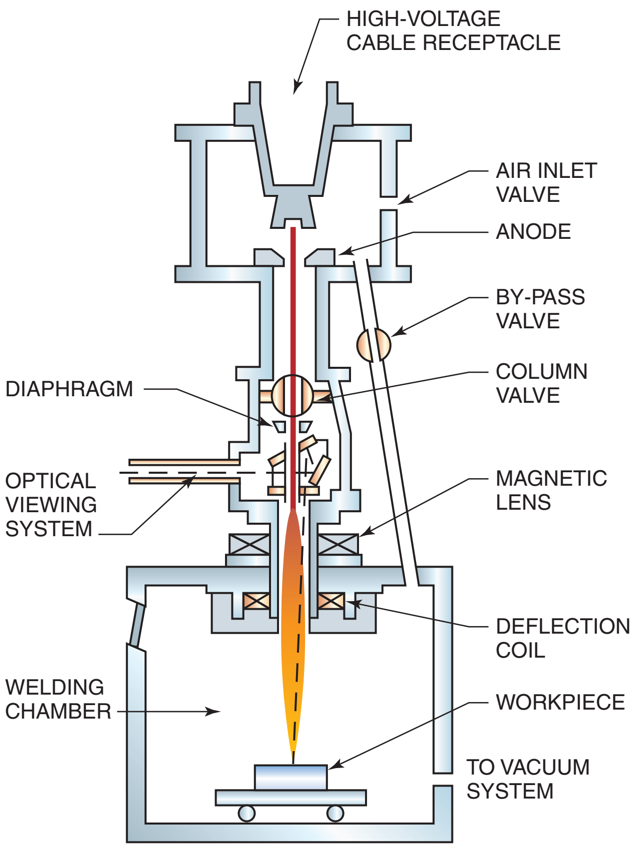


FIGURE 30-26 Schematic illustration of electron beam gun column.

position of the seam during the welding operation and precisely corrects for the degree of misalignment.

Assuming the piece is driven along the x-axis, **Figure 30-27**, electromagnetic deflection will move the electron beam transversely to the welding motion. As the misaligned seam moves in a linear direction along the axis, the seam tracker interprets the amount of deviation from the theoretical centerline and corrects the deflection of the beam to match the exact position of the seam at any instant.

Basically, the work is moving on the welding axis, and the beam is scanning on the y-axis. However, all motions are interchangeable as selected so that the welding motion may be on the gun, and correction may still be accomplished by moving the beam.

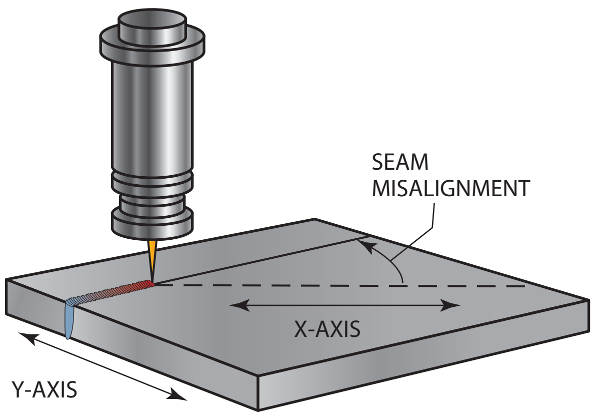


FIGURE 30-27 Seam-tracking system.

ULTRASONIC WELDING

Ultrasonic welding (USW) is a process for joining similar and dissimilar metals by introducing high-frequency vibrations into the overlapping metals in the area to be joined. Fluxes and filler metals are not required, electrical current does not pass through the weld metal, and only localized heating is generated. The temperature produced is below the melting point of the materials being joined. Thus, no melting occurs during the welding cycle.

The most common welds made with this process include spot, overlapping spot, continuous seam, and ring welds. The pieces to be welded are clamped between the welding tip and a hard surface, which serves as an anvil. High-frequency energy is fed to a transducer, which converts it to vibrations. The welding tip is attached to the transducer. The coupling system and welding tip form a unit that is referred to as a sonotrode, **Figure 30-28**. The welding tip oscillates in a plane essentially parallel to the joint interface. Transverse (shear) waves in the material produce the weld. Vertical (compression) waves are not effective in ultrasonic welding of metals.

The ultrasonic vibrations combined with the static clamping force cause dynamic shear stress in workpieces. When these shear stresses are great enough, local plastic deformation of the metal occurs at the interface. Surface films of oxide coatings are shattered and dispersed, and pure base metal contact is achieved. A true metallurgical bond is then formed in the solid state without melting the parent metal.

Continuous seam welding is done with a rotating, disk-shaped sonotrode tip. Either a counter-rotating roller anvil or a table-type anvil is also used. The entire tip assembly rotates so that the peripheral speed of the sonotrode tip matches the traversing speed of the workpiece.

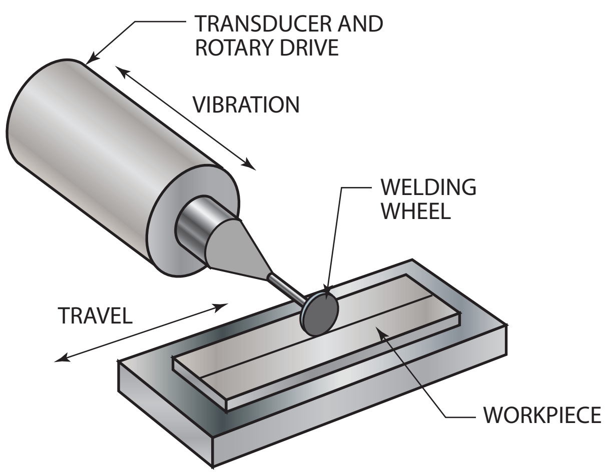


FIGURE 30-28 Ultrasonic seam welding.

The equipment used in this type of welding consists of the following: (1) a power supply or frequency converter that converts 60-Hz (60 cycles per second) line power into high-frequency electrical power and (2) a transducer that changes high-frequency electrical power to rapid vibrations. Welding speeds can range from a few feet per minute to 400 ft per minute (0.3 m per minute to 131 m per minute) for continuous seam welding. Times range from 0.005 sec to 1.0 sec for spot welding.

ULTRASONIC WELDING (USW) APPLICATIONS

Ultrasonic welding has many applications in the assembly of electrical products. Typical applications include the following:

- Attaching oxide-resistant contact surface buttons to switches
- Attaching leads to coils of foil, sheet, or wire made of aluminum
- Attaching very fine wire leads and elements to other components

Figure 30-29 shows an ultrasonic spot welder used to perform the types of welds just listed. In the plastics field (packaging), ultrasonic welding is used for both spot and continuous seam fabrication and for closures on various types of foil or plastic envelopes and pouches.

Various positive drive tip configurations can be designed for specific joint requirements. Applications of the process to aluminum welding include attaching thin ribs to cylinders, welding two pairs of leads at once, and joining two gears and one spacer in a single weld. Attachment of aluminum parts or brackets to stainless steel walls is another job readily performed by ultrasonic welding.

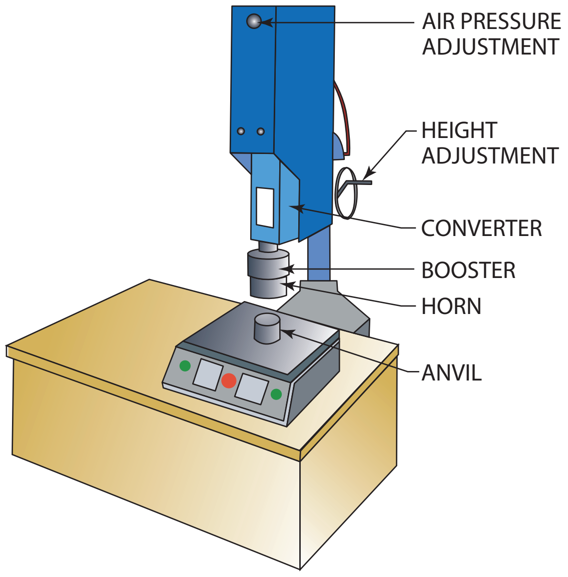


FIGURE 30-29 Ultrasonic spot welder.

Ultrasonic welding is used for materials with thicknesses up to approximately 1/8 in. (3 mm).

> **NOTE**
>
> Ultrasonic welding is the most commonly used process to join the two halves of plastic product packaging. It is indicated by a narrow, approximately 1/4-in. (6-mm) -wide band of surface deformation where the weld occurred.

INERTIA WELDING PROCESS (FRW-I)

Inertia welding is a form of friction welding. In **inertia welding**, one workpiece is fixed in a stationary holding device, **Figure 30-30**. The other is clamped in a spindle chuck. When the spindle motor is energized, it spins rapidly. At a predetermined speed, power to the spindle motor is cut, as shown in **Figure 30-31A**. One part is then pressed against the other piece. Friction between the parts causes the spindle to decelerate and quickly stop, converting stored energy to frictional heat. Enough heat is formed to soften, but not melt, the faces of the part, **Figure 30-31B**.

An accurate heating rate can be obtained because inertia can be controlled to supply whatever energy is needed.

Until rotation ceases, the two parts cannot bond. The compression force upsets the metal interface, forcing out any impurities or voids. The heat-affected zone is narrow, **Figure 30-31C**. The flash may or may not be cut off. The weld is formed when the spindle stops, as shown in **Figure 30-31D**.

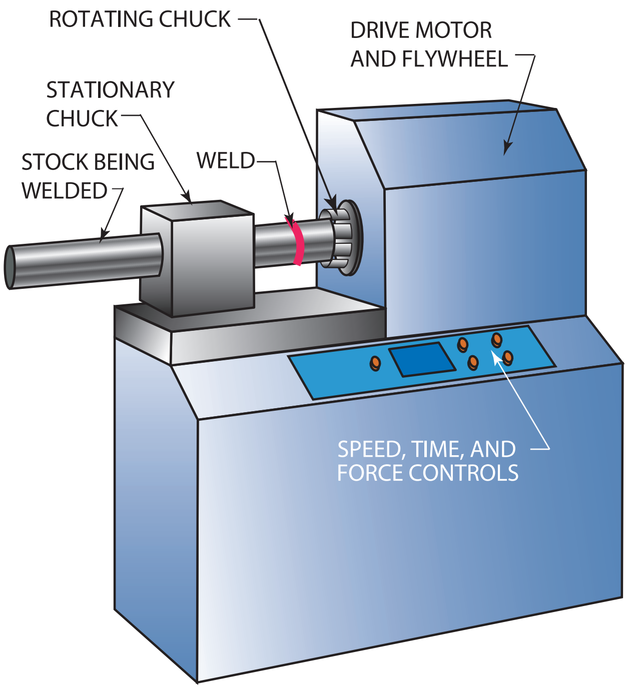


FIGURE 30-30 Inertia welder.

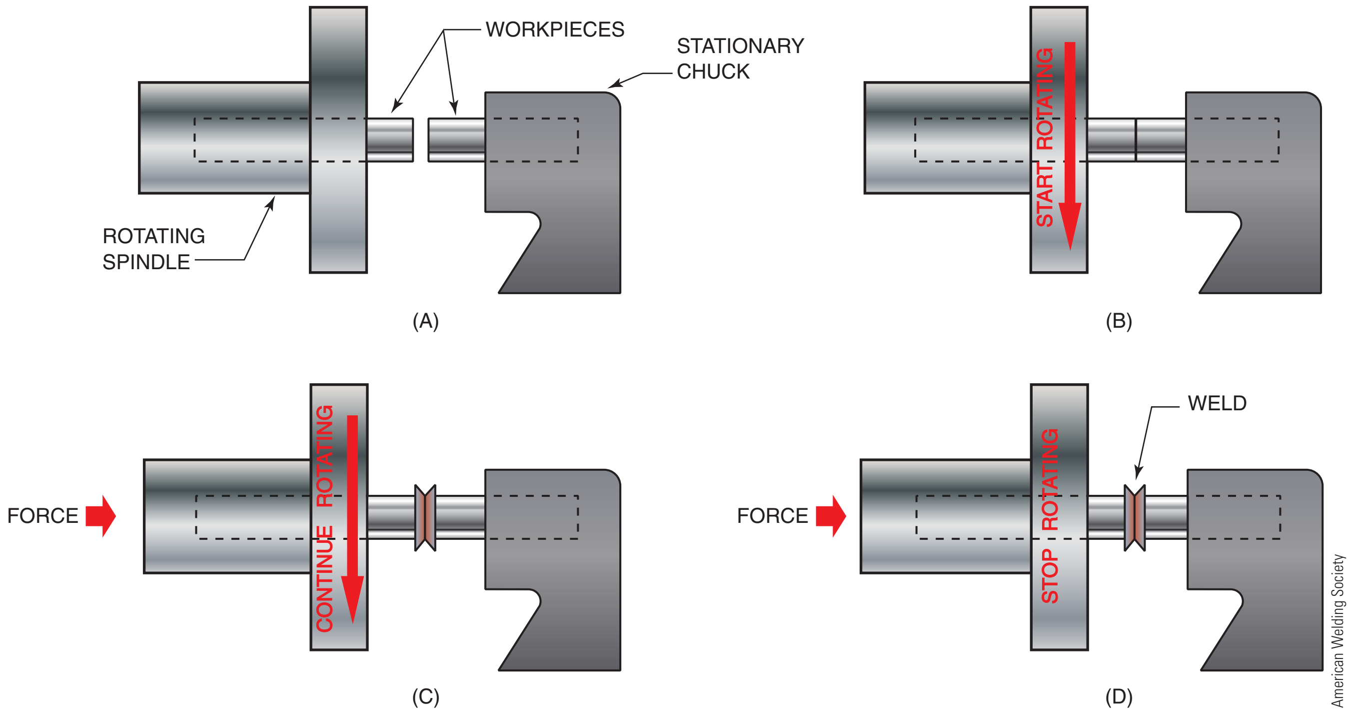


FIGURE 30-31 Inertia welding process. (A) One part is clamped onto the stationary chuck and the other is in the rotating spindle. (B) Rotating spindle begins spinning. (C) Force is applied against the stationary part. (D) Once friction has sufficiently heated the mating surfaces, the rotating spindle is quickly stopped.

A graph of speed, torque, and upset (change in workpiece length) during the weld period will show what happens, **Figure 30-32**. The curves start when the two pieces come together, after flywheel acceleration.

At first, there is a small torque peak and a corresponding change in the length of the parts. This is when initial temperature buildup occurs.

Torque then drops back and is fairly constant. During this period, a state of near-equilibrium exists when energy from the rotating mass is being converted to heat at the same approximate rate as it is being conducted away. Little upset occurs during this time.

Finally, the speed drops to a point where heat penetration does not keep up with heat dissipation and the faces cool slightly. The torque peaks sharply as the weld bonds are formed and broken. Most of the upset occurs just before the spindle stops. A solid state weld is created as the now stationary parts are pressed together.

The inertia welding process produces a complete interface weld of superior quality. The welding conditions must be consistent so that human judgment is removed in production work. The technique has been applied successfully to super alloys as well as to standard metals.

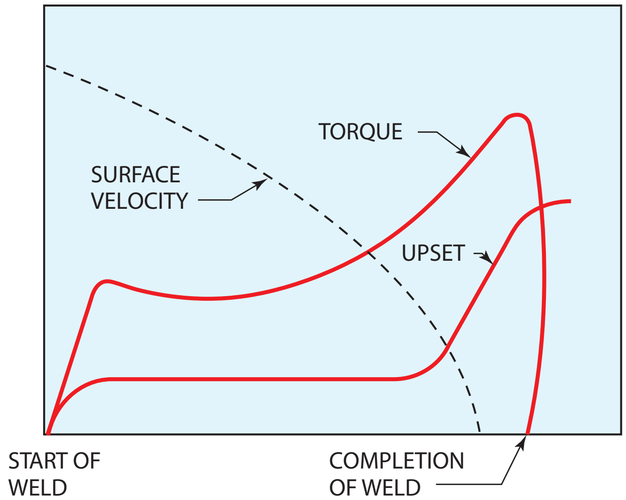


FIGURE 30-32 Chart shows what happens during inertia welding process.

Inertia Weld Bond Characteristics

Microscopic examination of the bond resulting from the inertia welding process shows the following three metallurgical characteristics:

- The weld zone is very narrow and has a fine-grained structure with no melt product or grain growth. These conditions indicate a hot-worked structure. When dissimilar metals are welded, often there are streaks of intermixed material near the outside diameter.
- Hardening phases from the rapid chilling are seen throughout the structure. The degree of hardening can be controlled but is often approximately the same as that achieved with a mild water quench.

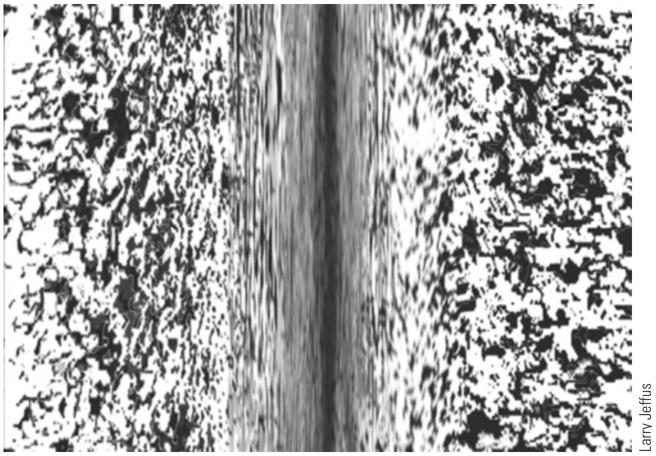


FIGURE 30-33 Mechanical mixing and grain refinement are evident in this 50× photomicrograph of an inertia weld between two pieces of ASE 51201 steel.

- There is a zone of varying grain structure between the heat-affected zone and the parent structure, **Figure 30-33**.

Table 30-1 lists some of the metals that can be joined by inertia welding.

Figure 30-34 shows a hydraulic piston rod assembly. The material is prechromed, cold-drawn tubing with the eye cut from tubing. In the past, this part was manufactured as a one-piece forging. Inertia welding of the parts produced an estimated savings of 50% per rod.

Some parts that have been joined by the inertia welding process are shown in **Figure 30-35** and **Figure 30-36**.

Similar Metals	
Carbon steels	Molybdenum
Sintered steels	Waspalloy
Stainless steels	Cobalt alloys
Tool steels	Titanium
Alloy steels	Zircalloy
Aluminum alloys	Inconel®
Copper	Nickel alloys
Brasses, bronzes*	
Dissimilar Metals	
High-speed steel to various steels	
Sintered steels to wrought steels	
316 stainless steel to Inconel®	
Stainless steel to medium- and low-carbon steels	
1100 or 6061 aluminum to medium-carbon steel	
Cobalt-base alloys to steel	
347 stainless steel to 17-4 PH	
Pure titanium to 302 stainless steel	
Copper to 1100 or 6061 aluminum	
Copper to medium-carbon steel	
Copper to various brasses	
Aluminum bronze to medium-carbon steel	
Nickel-base alloys to steel	

*Except bearing types.

TABLE 30-1 Partial List of Metals Joined by Inertia Welding

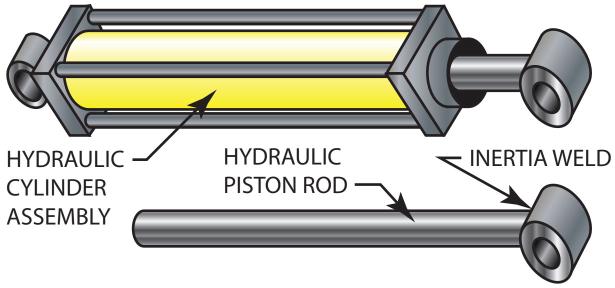


FIGURE 30-34 Hydraulic piston rod inertia welded assembly.

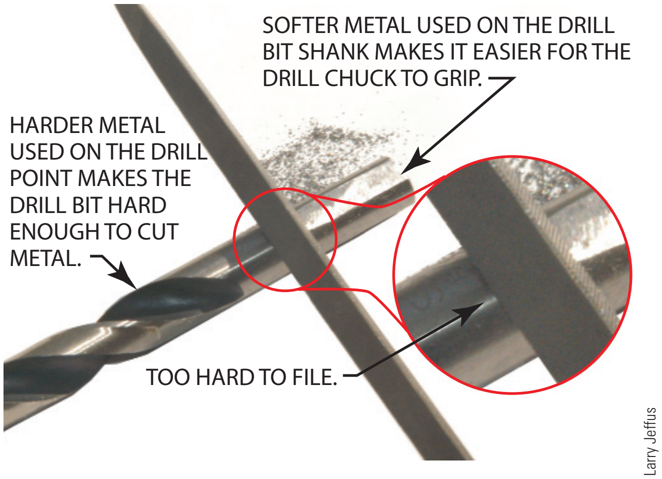


FIGURE 30-35 Drill bit shank and drill tip are inertia welded together.

FIGURE 30-36 Automatic engine valves.

The drill bit shown in Figure 30-36 is made up of two different types of metal. The cutting bet end is high-carbon steel and the shank is much softer. A file will only polish the surface of the high-carbon end but can easily cut the softer end.

Figure 30-36 shows an automotive engine valve with a 21-4-N head welded to an SAE 8645 stem. This part was formerly welded by the flash butt process. Inertia welding production methods produce 600 welds per hour.

Advantages of the Process

Some of the advantages of the inertia welding process are as follows:

- Superior weld.
- A very narrow heat-affected zone adjacent to the weld.
- Uniform production welds.
- Fast production welds.
- Clean operation.
- Lowest cost of energy.
- Minimum skill required to operate the welder.
- The amount of upset of parts can be controlled to close tolerances.
- A complete interface weld can be obtained.

Applications of this process include welding dry bearing materials such as oxides and leaded bronzes. Metals that cannot be hot-forged can also be joined by inertia welding.

LASER BEAM WELDING (LBW)

In **laser beam welding**, **Figure 30-37**, fusion is obtained by directing a highly concentrated beam of coherent light to a very small spot. Laser beams combine low-heat input (0.1 to 10 J) with high-power intensity of more than 10,000 W per square centimeter (considerably more than the electron beam). Due to the fact that the heat is provided by a beam of light, there is no physical contact between the workpiece and the welding equipment. It is possible to make welds through transparent materials.

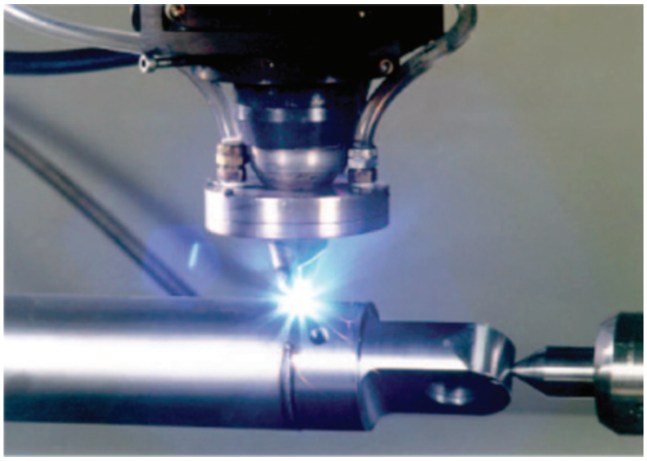


FIGURE 30-37 Gas filter, laser welded.

The ease with which the beam can be directed to any area of the work makes laser welding very flexible. In the manufacture of complex forms, for example, it is possible to move the focused laser beam under digital control to seam weld any desired shape. The proven high quality of laser welds, along with the flexibility and the comparatively moderate cost of laser welding equipment, has helped to increase their role in microelectronics and other light-gauge metal welding applications.

Laser welding of high-thermal conductivity materials, such as copper, is not difficult to do. The extremely concentrated laser heat will melt the metal locally to make a weld or will vaporize the metal to drill a keyhole. The keyhole allows the laser light to extend deeply into the base metal for deeper penetration.

Laser Welding Advantages and Disadvantages

Laser welding has some distinct advantages and disadvantages when compared to other welding processes. Electron beam welding is the only method that rivals the heat output of a laser. Generally, however, electron beam welding must operate in a vacuum. Because the laser beam is a light beam, it can operate in air or any transparent material, and the source of the beam need not even be close to the work. The material being welded need not be an electrical conductor that limits most other processes or even part of an electrical or a mechanical circuit. However, the light may be diffused by the welding vapors, so techniques to bypass the vapors have been developed.

Laser welds are small, sometimes less than 0.001 in. (0.0254 mm). Laser welding is used to connect leads to elements in integrated circuitry for electronics. Lead wires insulated with polyurethane can be welded without removing the insulation.

Using the laser welding process, it is possible to weld heat-treated alloys without undoing the heat treatment.

This method of welding can be used to join dissimilar metals. Metals that are difficult to weld, such as tungsten, stainless steels, titanium alloys, Kovar, nickel alloy, aluminum, and tin-plated steels, can also be successfully welded by this process.

An optical system is used to focus the beam on the workpiece. The actual control of the welding energy is done by a switch.

Laser Beam

The laser is based on the principle that atoms in certain crystals and gases can be made to release a coherent, monochromatic (single-wavelength) energy when they are excited. The output is self-amplified in the laser because the excited atoms release their energy much more rapidly when stimulated by light emitted by neighboring atoms, **Figure 30-38**.

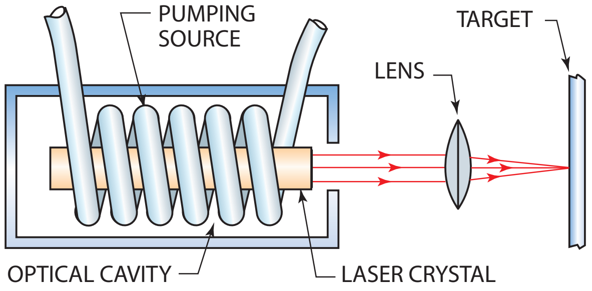


FIGURE 30-38 Schematic diagram of laser welder.

The early lasers all used a synthetic ruby rod as the material that produced the laser light. Today, a large number of materials can be used to produce the laser. These materials include common items such as glass and exotic items such as neodymium-doped yttrium aluminum garnet (Nd:YAG), often referred to as a YAG laser.

Laser Beam Heat Treating

The laser beam can be used to heat the surface of the materials so they can be hardened. Most laser beam hardening is performed on smaller parts that cannot be heat-treated in a normal manor or when only limited areas of a larger part need to be hardened. Following are some advantages of laser beam heat treating:

- The highly focused laser beam's heat can be used to heat treat the teeth of very small gears.
- Very hard and thin surfaces are supported by strong, more ductal substrata; this duplex material provides the harness needed to resist ware and the strength to resist fracturing, **Figure 30-39**.
- The very fast localized heating results in little or no distortion after heat treating.
- There is no electric current that might damage sensitive electronic parts that are being welded on or nearby.

PLASMA ARC WELDING (PAW)

The term *plasma* should be defined in its electrical sense. A gas, or plasma, is present in any electrical discharge if sufficient energy is present. The plasma consists of charged particles that transport the charge across the gap.

The two outstanding advantages of plasmas are higher temperature and better heat transfer to other objects. The higher the temperature differential between the heating fluid and the object to be heated, the faster the object can be heated.

In **plasma arc welding (PAW)**, a plasma jet is produced by forcing gas to flow along an arc restricted electromagnetically as it passes through a nozzle, **Figure 30-40**. The stiffness of the arc is increased by its decreased cross-sectional area. As a result, the welder has better control of the weld pool. By forcing the gas into the arc stream, it is heated to its ionization temperature, where it forms free electrons and positively charged ions. The plasma jet produced resembles a brilliant flame. The tip of the electrode is situated above the opening in the torch nozzle that constricts the arc. A plasma welding installation is shown in **Figure 30-41**. The plasma jet passing through the restraining orifice has an accelerated velocity.

Plasma arc welding can have 15 amps or less for extremely fine welds in thin metals or it can have more

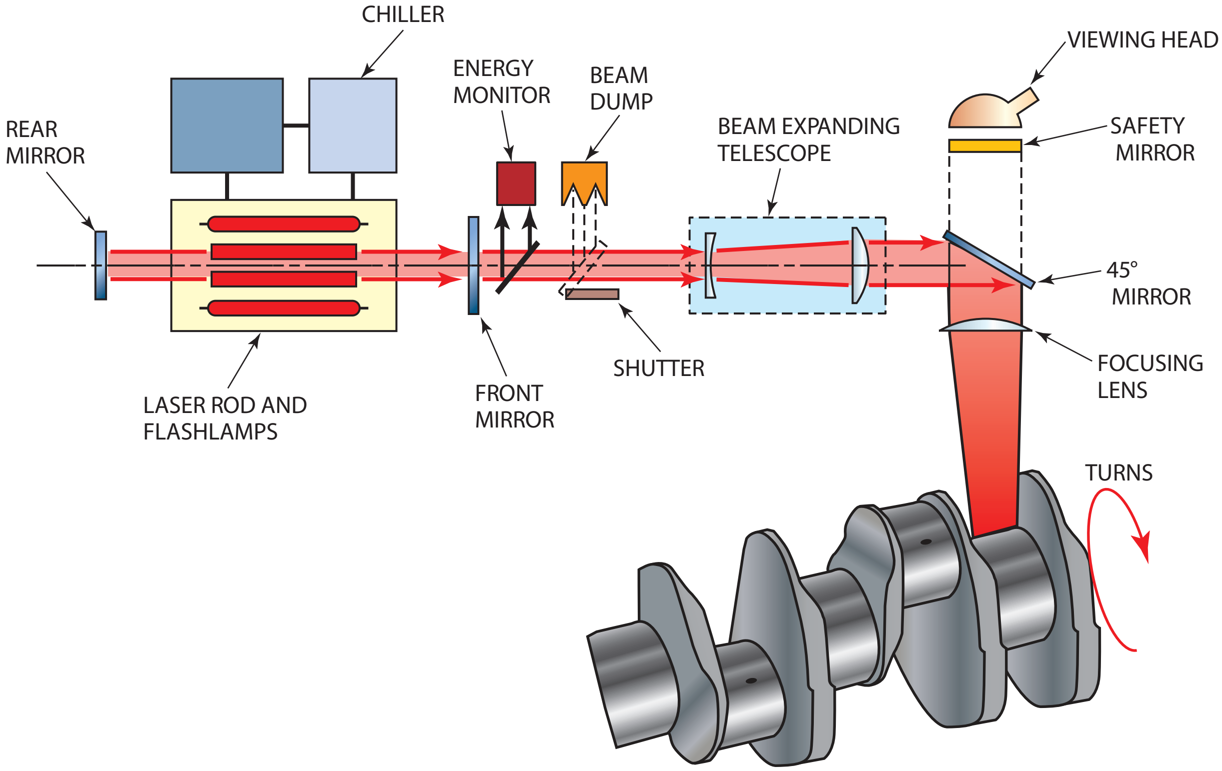


FIGURE 30-39 Diagram of laser surface hardening of engine crankshaft journals.

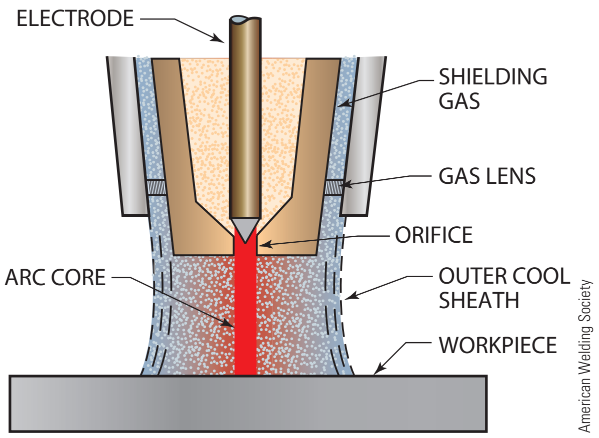


FIGURE 30-40 Schematic diagram of plasma welding process.

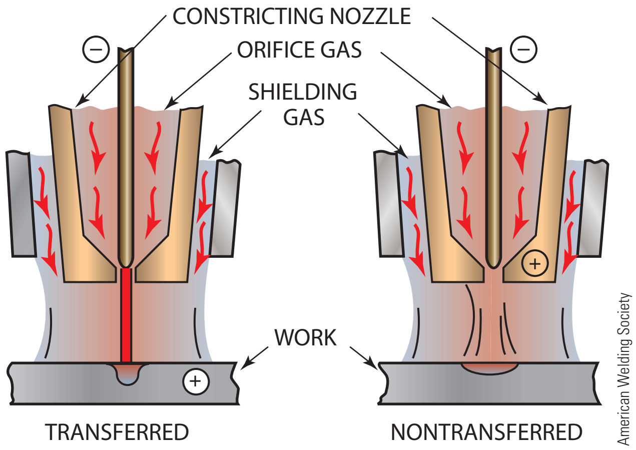


FIGURE 30-41 Transferred and nontransferred plasma arc modes.

than 100 amps, which allows it to make full-penetration welds in thick sections. For example, it is possible to make a welded butt joint in metal with a thickness of up to 1/2 in. (13 mm) in a single pass. Plasma arc welding is similar to GTA welding, but plasma's high temperature makes it much faster than GTAW.

Any known metal can be melted, even vaporized, by the plasma jet process, making it useful for many welding operations. This process can be used to weld carbon steels, stainless steels, Monel, Inconel, aluminum, copper, and brass alloys.

The plasma process is most often used for cutting (see Chapter 8).

STUD WELDING (SW)

Stud welding is a semiautomatic or automatic arc welding process. An arc is drawn between a metal stud and the surface to which it is to be joined. When the end of the stud and the underlying spot on the surface of the work have been properly heated, they are brought together under pressure.

The process uses a pistol-shaped welding gun, which holds the stud or fastener to be welded. When the trigger of the gun is pressed, the stud is lifted to create an arc and is then forced against the molten pool by a backing spring. The operation is controlled by a timer. The arc is shielded by surrounding it with a ceramic ferrule, which confines the metal to the weld area.

In the welding operation, a stud is loaded in the chuck of the gun, and the ferrule is fastened over the stud. The gun is then placed on the workpiece. The action of the gun when the trigger is squeezed causes the stud to pull away from the workpiece, resulting in an arc. The arc melts the end of the stud and an area on the workpiece. At the correct moment, a timing device shuts off the current and causes the spring to plunge the stud into the molten pool, which freezes instantly. The gun is then released from the stud and the ferrule knocked off.

THERMAL SPRAYING (THSP)

Thermal spraying is the process of spraying molten metal onto a surface to form a coating. Pure or alloyed metal is melted in a flame or an electric arc and atomized by a blast of compressed air. The resulting fine spray builds up on a previously prepared surface to form a solid metal coating. Because the molten metal is accompanied by a blast of air, the object being sprayed does not heat up very much. Therefore, thermal spraying is known as a "cold" method of building up metal, **Figure 30-42**.

Thermal Spraying Equipment

A thermal spraying installation requires, at a minimum, the following equipment: air compressor, air control unit, air flowmeter, oxyfuel gas or arc equipment, and exhaust equipment, **Figure 30-43**.

The three types of guns available for use in the thermal spraying process are wire guns, powder guns, and crucible guns.

The wire gun uses metal in the form of wire. Wire sizes range in diameter from 20 gauge to 3/16 in. (4.8 mm). These guns can spray from 4 lb (2 kg) to 12 lb (6 kg) of metal per hour.

The flame gun consists of the following parts: (1) an oxyfuel gas torch with a hole for wire through the center of the tip; (2) a high-speed turbine that drives a pair of knurled rolls equipped with reduction gears to feed wire into the flame at the correct rate; and (3) an "air cap" that encloses the tip of the torch and directs a blast of air to pick up and project the fine molten particles against the workpiece, as shown in

FIGURE 30-42 Rebuilding a worn crankshaft bearing with a Mogul Tube jet thermal spraying gun.

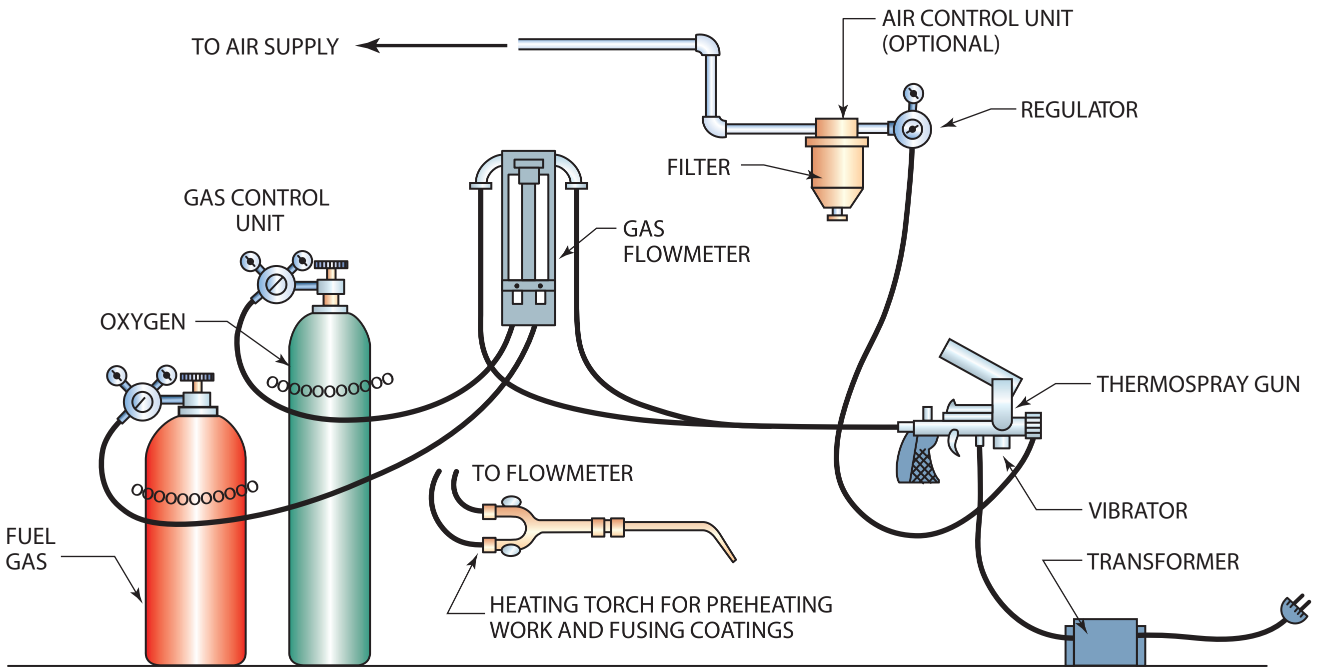


FIGURE 30-43 Complete thermal spray installation.

FIGURE 30-44 Powder-type thermal spray gun.

Figure 30-44. Oxyacetylene gas is most commonly used for the oxyfuel flame. However, other fuel gases such as hydrogen, propane, or natural gas may be used.

Thermospray (Powder) Process

During the past several years, the development of equipment, materials, and methods has greatly broadened the scope of powder spraying. Now a wide range of alloys and ceramics can be applied at speeds and costs that are economically feasible.

The wire type of flame spray equipment is limited to those materials that can be formed into wires or rods. In contrast, the thermospray process permits the use of metals, alloys, and ceramics in powder form.

Thermospray Gun

This type of gun, **Figure 30-45**, usually requires no air. Two lightweight hoses are used to supply oxygen and fuel gas. The powder is fed from a reservoir attached directly to the gun, thus eliminating separate hoppers and hoses. A small reservoir is attached to the gun for hand use, and a larger one is provided for lathe-mounted guns or for large-scale production work. An air cooler may be attached to the gun to reduce overheating of small work or thin sections. Extensions are available for coating inside diameters. A trigger-actuated vibrator, which is attached to the gun, is used with ceramic powders and with some metal powders.

By changing powder orifices, any required powder feed may be obtained. This permits spraying the entire range of metals, alloys, ceramics, and cements that can be applied by the thermospray process. Several different types of nozzles can be used for various purposes.

Acetylene is generally used, but hydrogen is required for some applications. The gun may be used as a torch for preheating light work. For large work and for the fusing of coatings of self-fusing alloys, high-capacity acetylene torches are used.

Torch Spraying

A spray metal torch is used for spraying small parts. The torch is made up of a hopper and a spray-control mechanism that can be attached to any conventional acetylene torch. Metal powder is placed in the hopper. The torch is lit and is then moved over the part to create the overlay, **Figure 30-46**. The powder passes into the acetylene flame, which converts it to a fluid state.

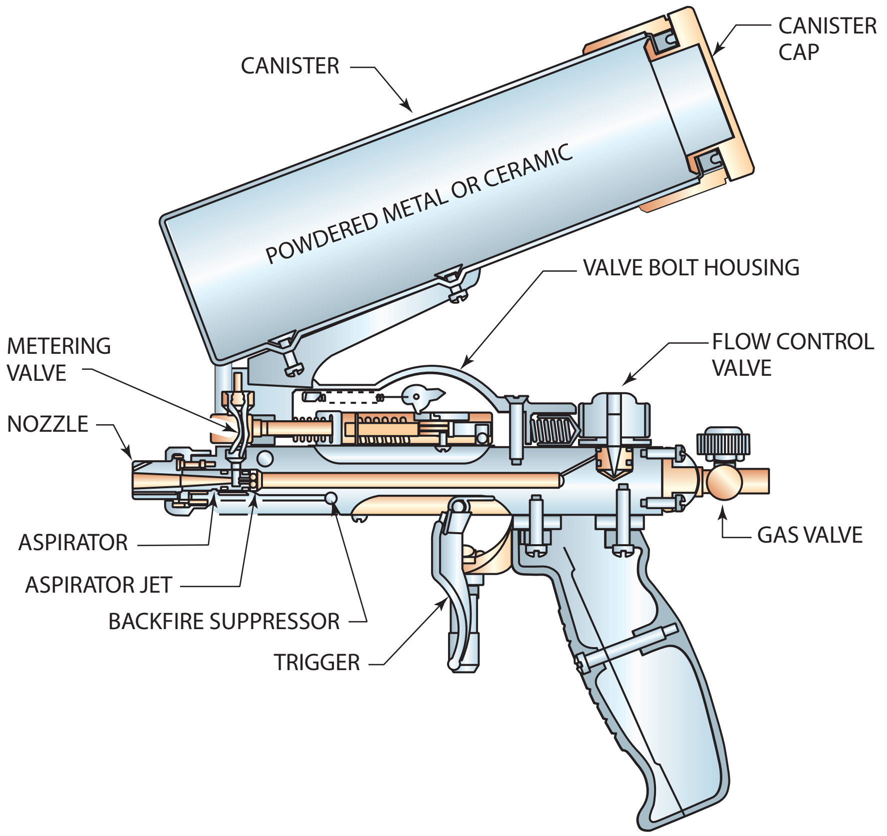


FIGURE 30-45 Schematic of thermospray gun for applying metals, ceramics, and hardfacing alloys.

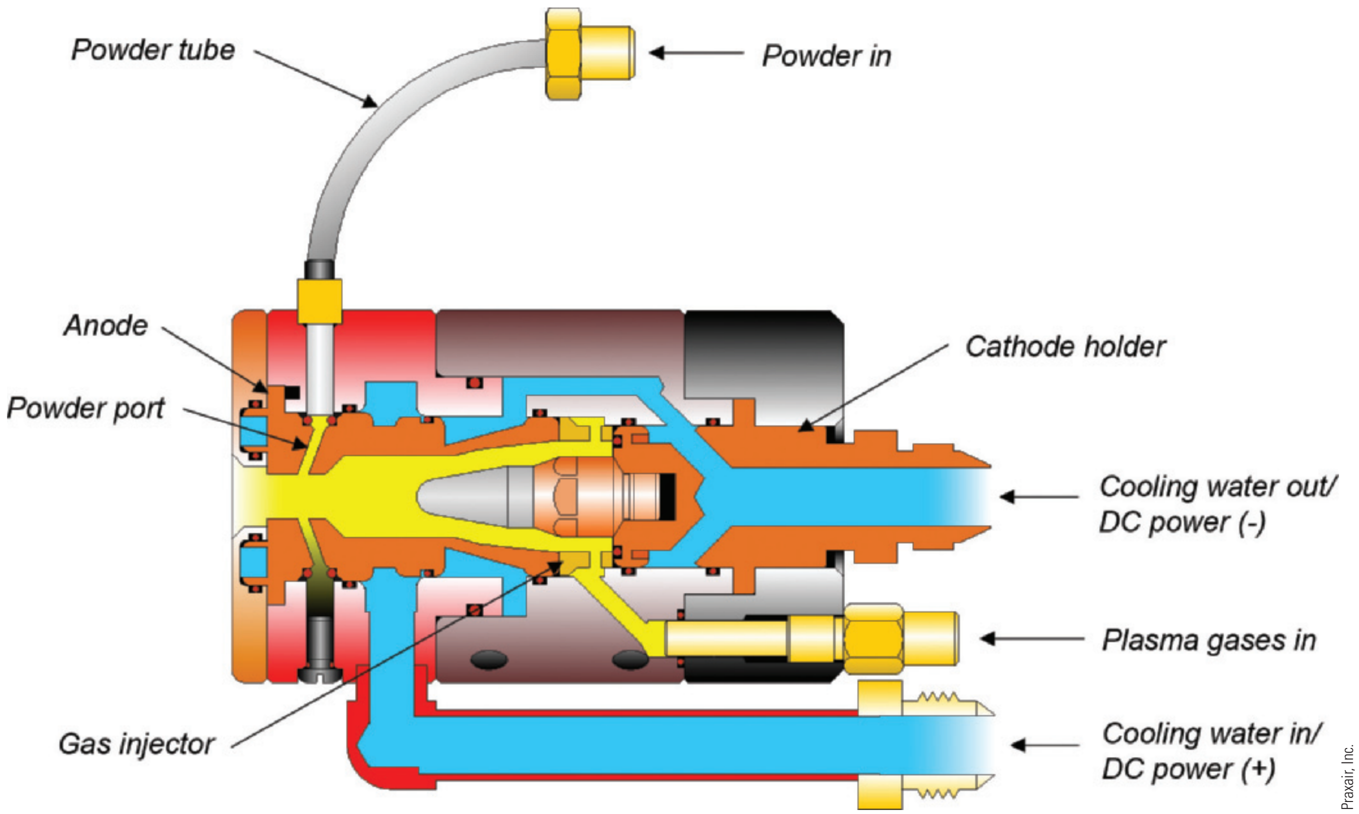


FIGURE 30-46 Schematic of plasma arc thermal spraying gun.

Applying Sprayed Metal

Metal that is sprayed is usually applied in layers less than 0.010 in. (0.25 mm) thick. Each layer is applied to a surface and bonds to the preceding layer. Greater reliability can be obtained by not trying to lay a heavy coating in one single pass.

Mechanized operation can usually be accomplished by mounting the workpiece in a lathe. The gun is then mounted on the tool post and traverses the workpiece by mechanized operation.

Plasma Spraying Process

Plasma is the term used to describe vapors of materials that are raised to a higher energy level than the ordinary gaseous state. Whereas gases consist of separate molecules, plasma consists of these same gases, which have been broken up and dissociated into ions and electrons.

The plasma spraying process (PSP), **Figure 30-47**, makes use of a spray gun that uses an electric arc contained within a water-cooled jacket. The plasma flame permits the selection of an inert, or chemically inactive, gas for the flame medium so that oxidation can be controlled during the application of the spray material.

The powder is fed into the plasma flame through the side of the nozzle. The high velocity of the flame propels the powder toward the surface to be coated. As this occurs, the ions and electrons of the plasma are recombining into atoms and releasing energy as heat. This heat is sufficient to melt the powder.

Coatings resulting from this process add extra life and superior resistance to heat, wear, and erosion on parts and products of almost any base material.

Thermal spraying techniques are used in applications that involve wear and high-temperature problems. Typical applications include missile nose cones, rocket nozzles, jet turbine cases, electrical contacts, jet engine burner cam clamps, and many aircraft parts.

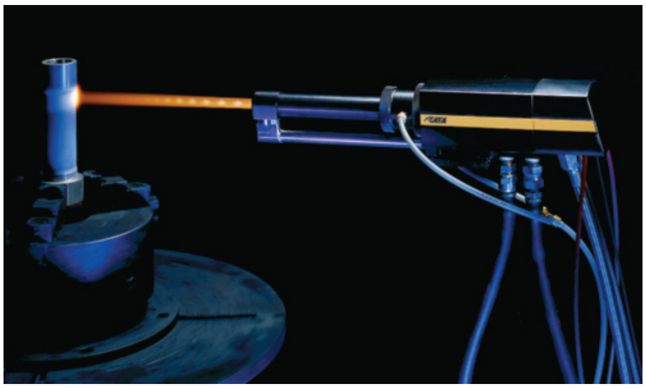


Image Courtesy of Praxair, Inc.

FIGURE 30-47 Kerosene-fueled gun that can produce extremely high coating densities.

COLD WELDING (CW)

Cold welding is a solid state process of welding. There is no heating or melting of the metal that forms the bond in this process. The weld takes place at room temperature.

The coalescence of the metal surfaces occurs as a result of the force applied. It is possible to join most soft, ductile metals using this method. Also, dissimilar metals such as aluminum to copper, iron to copper, and so on can be joined.

Early cold welding was primarily done as spot welds, but today it is possible to make lap, edge, and butt joints. Spot welds can be made using portable, hand-operated tools, **Figure 30-48**. Other types of joints require special machines.

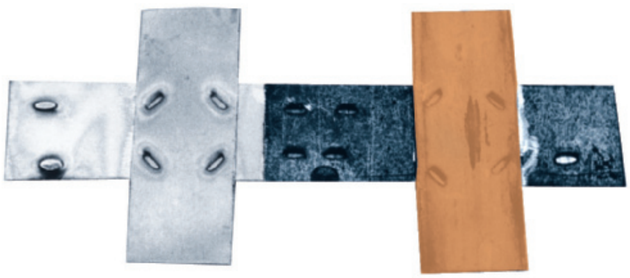
A major factor in the success of the cold weld is that the surface oxides and other contaminations should be removed before welding. The best method to clean the surface is with a power wire brush. The surface must not be touched after it is cleaned, and the welding should be done as soon as possible after cleaning.

THERMITE WELDING

Thermite welding (TW) is a process that uses an exothermic reaction to develop a high temperature. This process is based on the great attraction of aluminum for oxygen. Aluminum can be used as a reducing agent for many oxides.

Larry Jeffus

(A)



Larry Jeffus

(B)

FIGURE 30-48 (A) Cold welding tool. (B) Cold welds made between aluminum, copper, and mild steel.

Thermite welding of rails is used throughout the world to join lengths of rails into continuous track. None of the other methods of joining and welding rails offers the advantages and service provided by thermite welding. The thermite welding process is widely used because of its high-quality welds, relative simplicity, portability, and economy.

Several companies make thermite welding products. The exact welding procedure must contain preheat temperature, chemical reaction time, charge size, joint spacing, and other essential welding variables, and must be obtained from the manufacturer's WPS for each product being used and rail type being welded.

Thermite compound consists of finely divided aluminum and iron oxide mixed in a ratio of 1:3 by weight. Alloys are added to the mixture to obtain the desired weld metal properties. The mixture is not explosive and can be ignited only at a temperature of 2800°F (1537°C). A special ignitor is used to start the reaction. After a chemical reaction has taken place, the melt attains a temperature of 4500°F (2482°C).

The products of the reaction are superheated iron alloy and alumina slag. The slag floats to the top and is not used in making the weld.

The rail ends must be cleaned, prepared, and aligned in preparation for welding. Cleaning must include the removal of all dirt, rust, oil, grease, paint, and other sources of possible contamination. Metal flaws such as burrs, chips, and rolled-over edges must be removed, **Figure 30-49**.

Rail end spacing, smoothness, and squareness are all important. The rail ends must be properly prepared for welding. The rail end face must be cut square, smooth, and parallel. It can be cut by sawing, abrasive disk, or oxyfuel gas cutting.

The rails must be secured in proper alignment to prevent their movement during the welding process. Vertical, horizontal, and joint gap alignments as well as the correct offset of the rails can be provided by special clamping and alignment devices, **Figure 30-50**.

Thermite welds are essentially steel castings. The hardware parts used in making a thermite weld consist of a crucible, mold, and slag pan and are all made from a refractory material. The **crucible** is a container designed to hold the thermite powder while the chemical reaction heats up before welding occurs. The **mold** is placed around the rail ends and sealed to hold the weld metal in place until it cools. The **slag pan** provides a container for the overflow of slag and any excess weld metal. The crucible can be designed as either reusable or for a one-time use. **Figure 30-51** illustrates the arrangement of a thermite welding setup.

Moisture of any kind such as rain, snow, ice, or even the slightest dampness can make the thermite process hazardous to use. If the powder, mold, crucible, slag pan, or track is damp, then a steam explosion may occur during the weld.

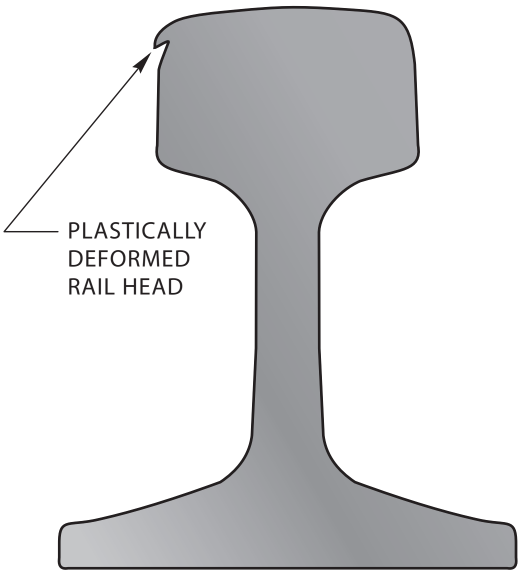


FIGURE 30-49 Plastic deformation of rail head occurs over time with use.

Larry Jeffus

FIGURE 30-50 Rail clamp used to align and hold rail ends for welding.

CAUTION

A steam explosion can cause serious injury or even death.

Refractory materials are designed to withstand the heat of welding but have relatively low mechanical strength. Care must be taken during their installation to not crack or break them by forcing, overtightening, or binding.

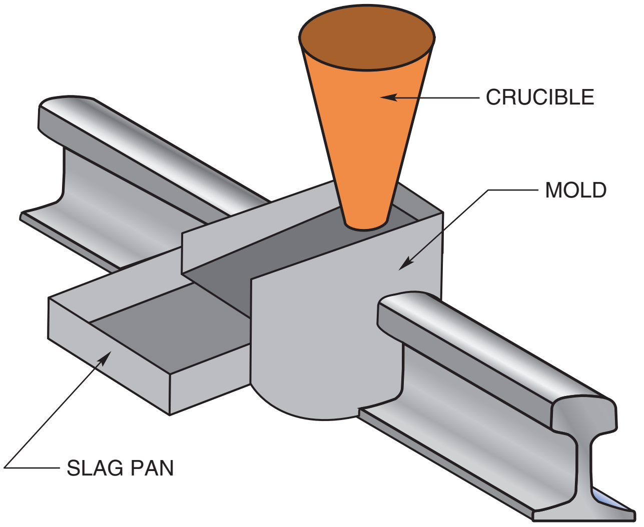


FIGURE 30-51 Thermite welding setup.

(A)

(B)

FIGURE 30-52 (A) Thermite welding. (B) Thermite weld after grinding.

CAUTION

Never use damaged or improperly fitted molds. Damaged molds present a serious hazard to everyone in the area. If the damaged mold fails during the thermite welding process, superheated metal and slag will be released. Because of the temperature and quantity of this material, it can cause steam explosions even from relatively dry ballast or soil. Such explosions can throw large quantities of molten material several feet from the weld.

Following the preheating of the rail ends to WPS recommended temperature, the thermite mixture in the crucible is ignited. When the metal is molten, the plug in the crucible collapses, and the metal flows into the mold. The weld metal temperature is approximately two-times the melting temperature of the base metal. When the weld metal flows into the joint, fusion takes place. After the deposited metal has cooled, the mold is removed and the riser and sprues are cut off, leaving the desired sound weld, **Figure 30-52**.

Thermite welding is also used to weld together ends of large reinforcement rods in concrete and to make welds in large sections where other methods of welding prove difficult.

The most unique application of thermite welding is used by the military. It uses a process to sabotage moving parts of equipment that were captured or that were going to be abandoned during battles.

HARDFACING

Hardfacing is defined as the process of obtaining desired properties or dimensions by applying, using oxyfuel or arc welding, an integral layer of metal of one composition onto a surface, an edge, or the point of a base metal of another composition. The hardfacing operation makes the surface highly resistant to abrasion.

There are various techniques of hardfacing. Some apply a hard surface coating by fusion welding. In other

techniques, no material is added but the surface metal is changed by heat treatment or by contact with other materials.

Several properties are required of surfaces that will be subjected to severe wearing conditions, including hardness, abrasion resistance, impact resistance, and corrosion resistance.

Hardfacing may involve building up surfaces that have become worn. Therefore, it is necessary to know how the part will be used and the kind of wear to expect. In this way, the proper type of wear-resistant material can be selected for the hardfacing operation.

When a part is subjected to rubbing or continuous grinding, it undergoes abrasion wear. When metal is deformed or lost by chipping, crushing, or cracking, impact wear results.

Selection of Hardfacing Metals

Many different types of metals and alloys are available for hardfacing applications. Most of these materials can be deposited by any conventional manual or automatic arc or oxyfuel welding method. Deposited layers may be as thin as 1/32 in. (0.79 mm) or as thick as necessary. The proper selection of hardfacing materials will yield a wide range of characteristics.

Steel or special hardfacing alloys should be used where the surface must resist hard or abrasive wear. Where surfacing is intended to withstand corrosion-type or friction-type wear, bronze or other suitable corrosion-resistant alloys may be used.

Most hardfacing metals have a base of iron, nickel, copper, or cobalt. Other elements that can be added include carbon, chromium, manganese, nitrogen, silicon, titanium, and vanadium. The alloying elements have a tendency to form carbides. Hardfacing metals are provided in the form of rods for oxyacetylene welding, electrodes for shielded metal arc welding, or in hard-wire form for automatic welding. Tubular rods containing a powdered metal mixture, powdered alloys, and fluxing ingredients can be purchased from various manufacturers.

Many hardfacing materials are designated by manufacturers' trade names. Some of the materials have AWS designations. AWS materials are classified into the following designations:

- High-speed steel
- Austenitic manganese steel
- Austenitic high-chromium iron
- Cobalt-base metals
- Copper-base alloy metals
- Nickel-chromium-boron metal
- Tungsten carbides

The coding system identifies the important elements of the hardfacing metal. The prefix *R* is used to designate a welding rod, and the prefix *E* indicates an electrode. Certain materials are further identified by the addition of digits after a suffix.

Hardfacing Welding Processes

Oxyfuel Welding In hardfacing operations, oxyfuel welding permits the surfacing layer to be deposited by flowing molten filler metal into the underlying surface. This method of surfacing is called sweating or tinning, **Figure 30-53**.

With the oxyacetylene flame, small areas can be hardfaced by applying thin layers of material. In addition, the alloy can be easily flowed to the corners and edges of the workpiece without overheating or building up deposits that are too thick. Placement of the metal can be controlled accurately.

The size of the weld is affected by many factors. These factors include the rate of travel, degree of preheat, type of metal being deposited, and thickness of the work.

Figure 30-54 shows the approximate relationship of the tip, rod, molten pool, and base metal during the hardfacing operation.

Iron, nickel, and cobalt-base alloys require a carburizing flame. Copper alloys and bronze call for a neutral or slightly oxidizing flame. Laps, blowholes, and poor adhesion of deposits can be prevented by a flame characteristic that is soft and quiet.

In all types of surfacing operations, the metal should be cleaned of all loose scale, rust, dirt, and other foreign substances before the alloy is applied. The best method of removing these impurities is by grinding or machining the surface. Fluxes may be used to maintain a clean surface. They also help to overcome oxidation that may develop during the operation.

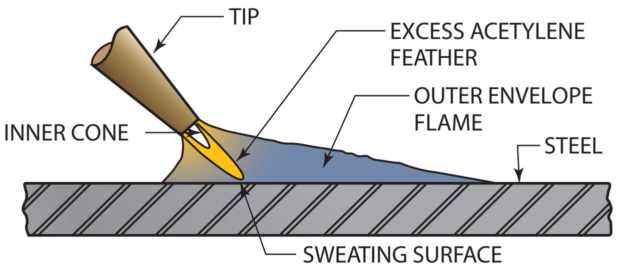


FIGURE 30-53 An example of how to produce sweating.

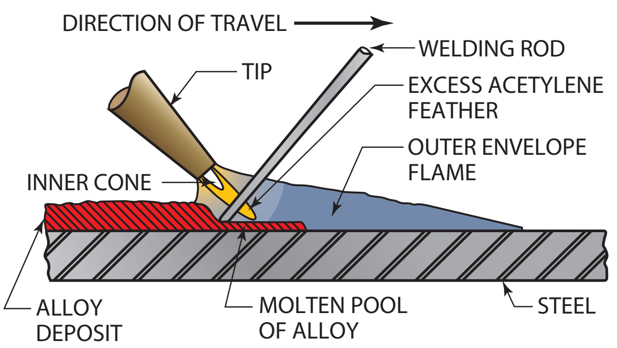


FIGURE 30-54 Approximate relationship of the tip, rod, and molten weld pool for forehand hardfacing.

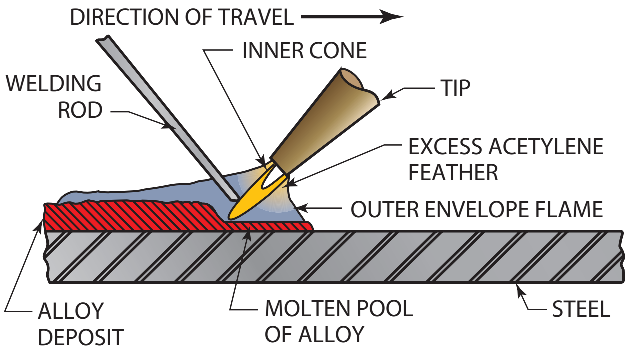


FIGURE 30-55 Backhand method of hardfacing.

Conventional methods may be used in holding the torch and rod. **Figure 30-55** shows the backhand method of hardfacing.

If the base metal is cast iron, it will not "sweat" like steel. Therefore, slightly less acetylene should be used. Alloys do not flow as readily on cast iron as they do on steel. Usually, it is necessary to break the surface crust on the metal with the end of the rod. A cast iron welding flux is generally necessary. The best method is to apply a thin layer of the alloy and then build on top of it.

The oxyacetylene process is preferred for small parts. Cracking can be minimized by using adequate preheat, postheat, and slow cooling. Shielded metal arc welding is preferred for large parts.

Arc Welding Hardfacing by arc welding may be accomplished by shielded metal arc, gas metal arc, gas tungsten arc, submerged arc, plasma arc, or other processes.

The techniques used for any one of these processes are similar to those used in welding for joining. The factor of dilution must be carefully considered because the composition of the added metal will differ from the base metal. The least amount of dilution of filler metal with base metal is an important goal, especially where the two metals differ greatly. Little dilution means that the deposited metal maintains its desired characteristics. When using alloys with high melting points, dilution of the weld metal is usually kept well below 15%.

Hardfacing by the arc welding method has many advantages, including high rates of deposition, flexibility of operation, and ease of mechanization.

Hardfacing may be applied to many types of metals, including low- and medium-carbon steels, stainless steels, manganese steels, high-speed steels, nickel alloys, white cast iron, malleable cast iron, gray and alloy cast iron, brass, bronze, and copper.

Quality of Surfacing Deposit

The type of service to which a part is to be exposed governs the degree of quality required of the surfacing deposit. Some applications require that the deposited metal contain no pinholes or cracks. For other applications, these requirements are of little importance. In most cases, the quality of the deposited metals can be very high. Steel-base alloys do not tend to crack, whereas other materials, such as high-alloy cast steels, are subject to cracking and porosity.

Hardfacing Electrodes

The proper type of surfacing electrode must be selected because one type of electrode will not meet all requirements. Most electrodes are sold under manufacturers' trade names.

Electrodes may be classified into the following three general groups:

- Resistance to severe abrasion
- Resistance to both impact and moderate abrasion
- Resistance to severe impact and moderately severe abrasion

Tungsten carbide and chromium electrodes are included in the first group. The material deposited is very hard and abrasive-resistant. These electrodes can be one of two types, either coated tubular or regular coated cast alloy. The tubular types contain a mixture of powdered metal, powdered ferro alloys, and fluxing materials. The tubes are the coated type. These electrodes are used with the electric arc.

Electrodes contain small tungsten carbide crystals embedded in the steel alloy. After this material is applied to a surface, the steel wears away with use, leaving the very hard tungsten carbide particles exposed. This wearing away of steel results in a self-sharpening ability of the surfacing material. Cultivator sweeps and scraping tools are among parts that are surfaced with this material, **Figure 30-56**.

Chromium carbide electrodes are tougher than tungsten carbide–type electrodes. However, chromium carbide electrodes are not as hard and are less abrasion-resistant. This material is too hard to be machined, but it has good corrosion-resistant qualities.

The electrodes in the second group are the high-carbon type. When used for surfacing, these electrodes leave a tough

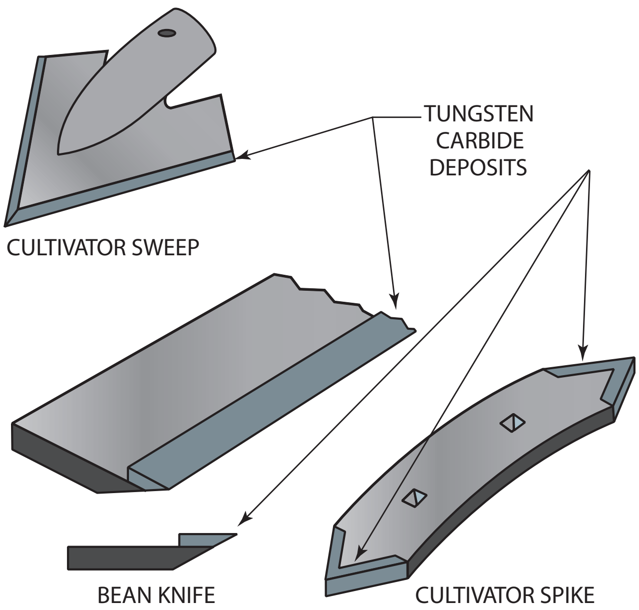


FIGURE 30-56 Farm tools that can be hardfaced with tungsten carbide electrodes to increase the life of the tools.

and very hard deposit. Examples of hardfaced products in this group include gears, tractor lugs, and scraper blades.

The third group of electrodes is used for surfacing rock-crusher parts, links, pins, railroad track components, and parts where severe abrasion resistance is a requirement, **Figure 30-57** and **Figure 30-58**. Deposits from these electrodes are very tough but not hard. It is this quality that seems to work-harden the hardfacing material but leaves the material underneath in a softened condition. Therefore, cracking generally is not a problem.

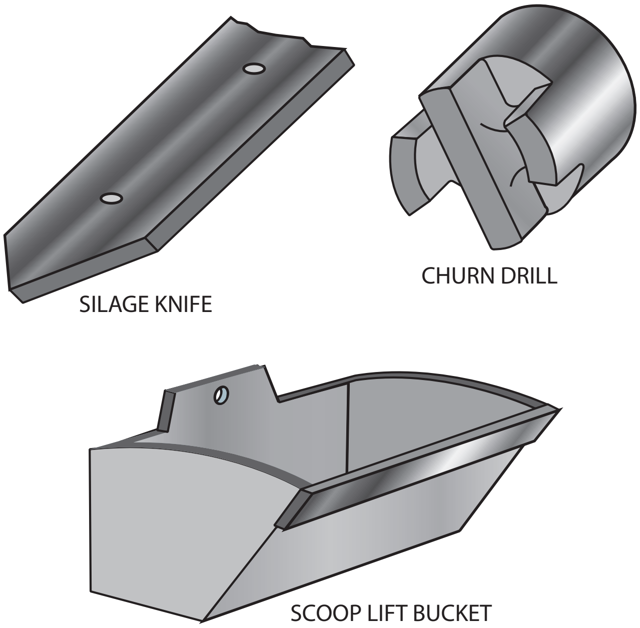


FIGURE 30-57 Products that are hardfaced to produce moderate impact resistance and severe abrasion resistance.

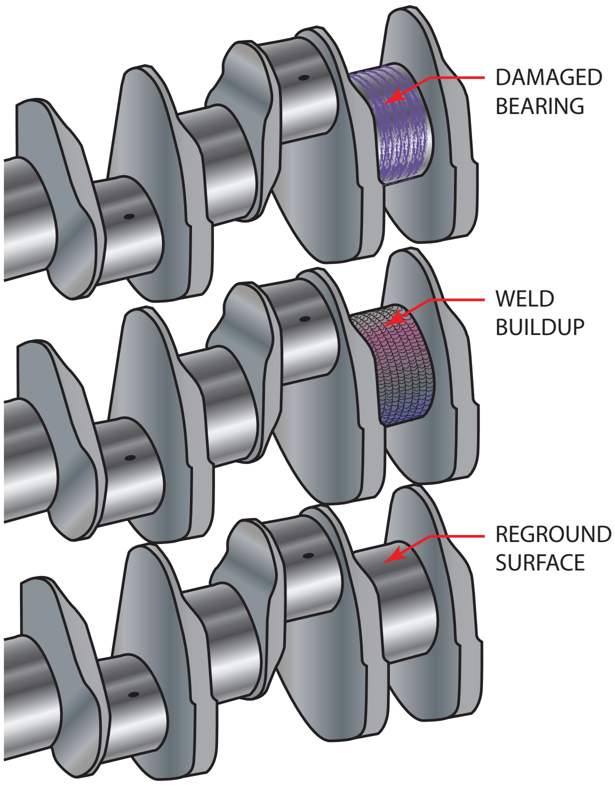


FIGURE 30-58 Bearing surfaces are built up on this crankshaft.

Shielded Metal Arc Method

1. Start the process by cleaning the surface.
2. Because most hardfacing electrodes are too fluid for out-of-position welding, the work should be arranged in the flat position.
3. Set the amperage so that just enough heat is provided to maintain the arc. Too much heat will cause excessive dilution.
4. Hold a medium-long arc, using either a straight or weave pattern. When a thin bead is required, use the weave pattern and keep the weave to a width of 3/4 in. (19 mm).
5. If more than one layer is required, remove all slag before placing other layers.

Hardfacing with Gas Shielded Arc

GTA, GMA, and FCA welding processes may be used in hardfacing operations. These three processes, in many instances, are better methods of hardfacing because of the ease with which the metal can be deposited. In addition, the hardfacing materials may be deposited to form a porosity-free, smooth, and uniform surface.

Where the job calls for cobalt-base alloys, the GTA method does an effective job. Very little preheating of the base is required. The GMA and FCA welding processes are somewhat faster than surfacing by GTA due to the fact that continuous wire is used.

Care must be exercised when using the GMA, FCA, and GTA welding processes for hardfacing to avoid dilution of the weld. Helium or a mixture of helium-argon normally produces a higher arc voltage than pure argon. For this reason, the dilution of the weld metal increases. An argon and oxygen mixture should be used for surfacing with the gas metal arc processes, and argon should be used with gas tungsten arc processes. When using FCAW, shielding may be provided as either shielding gas or self-shielding. The self-shielding hardsurfacing process is used when working outdoors because of its ability to better resist the effect of light winds.

FRICTION STIR WELDING (FSW)

Friction stir welding (FSW) is a solid state welding process. A weld is formed between the joining surfaces as the result of the mechanical stirring of the metal without the metal melting. Although the metal is not melted, friction between the tool and the metal does heat it up to its plastic state. The process uses a wear-resistant tool capable of withstanding the heat of friction generated during the weld, **Figure 30-59**.

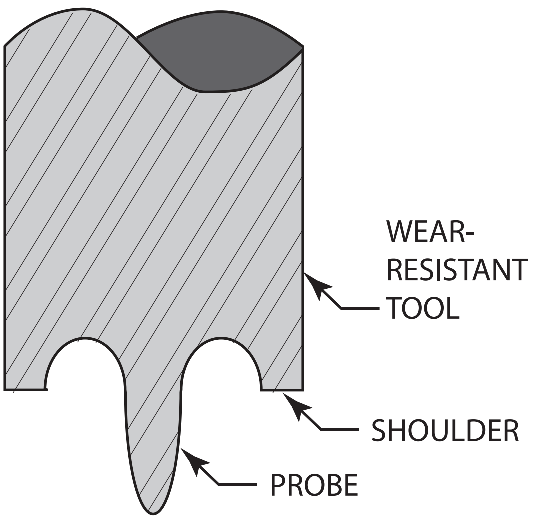


FIGURE 30-59 Cutaway of a friction stir welding tool.

To make an FS weld, the base metal must be tightly clamped together with a backing plate held tightly behind the joint. The backing plate keeps the weld metal from being pushed out of the back side of the joint. The spinning tool is slowly moved or plunged into the base metal, **Figure 30-60A**. The tool is moved at a constant rate along the joint, **Figure 30-60B** and **C**. The weld can be completed by moving the tool all the way across the joint or the tool can be raised up at the end of the weld. Either way of ending the weld will leave a probe cavity, **Figure 30-60D**. There are several techniques that can be used to solve the problem of the probe cavity. One technique is to use a runoff tab at the end of the joint. Another technique is to move the tool off of the joint onto an area of scrap before it is stopped or to move the tool off the joint where the probe cavity will not affect the welded joint.

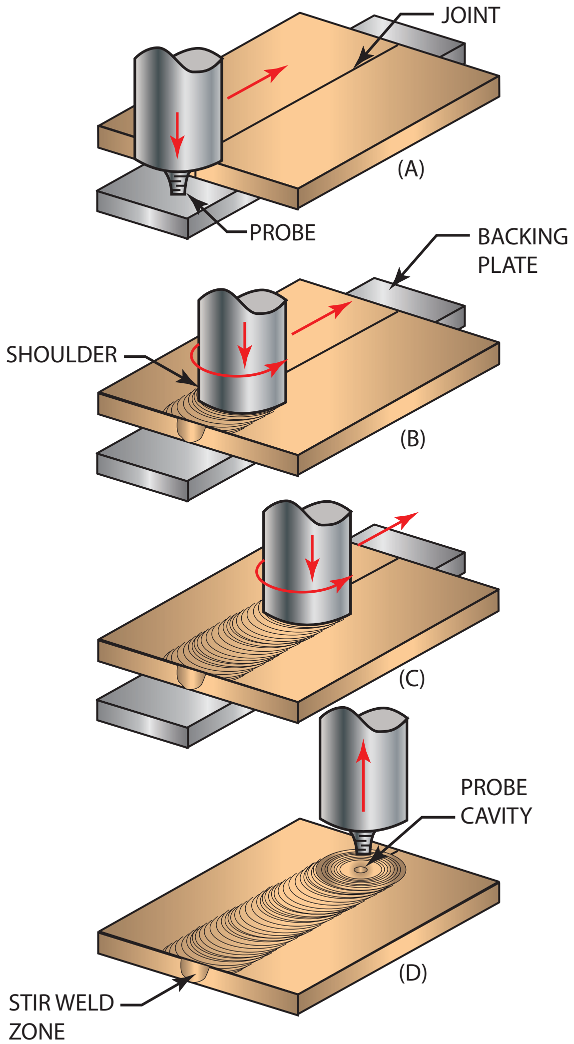


FIGURE 30-60 Sequence of a friction stir weld. (A) Downward force is applied to the friction stir welding probe as it begins rotating. (B) The shoulder of the friction stir welding probe prevents the weld metal from escaping from the joint. (C) The welding tool progresses along the joint until the joint is complete. (D) The tool is raised at the end, leaving a cavity where the probe tool was removed.

MAGNETIC PULSE WELDING (MPW)

Magnetic pulse welding is a solid-state form of welding. The term solid state welding relates to the fact that neither surface that is being joined melts. Although MPW has been around since the 1970s, it has not been used very much until recently. When the magnetic field is created it flows over the top metal sheet, forcing it to be slammed into the base plate, **Figure 30-61**. As the magnetic field flows across the fly plate it is forced downward at an angle called the collision angle. The force is so intense that waves form along the metal surface that interlock to hold the two surfaces together. Light surface oxides or impurities are thrust out ahead of the interface of the weld in a jetting action. The entire process is completed in a few milliseconds.

Since there is no fusion between the surfaces being joined there is no heat-affected zone. This allows many different metals to be joined that could not be joined using typical fusion welding processes. Because there is no heat-affected zone, the metals maintain their mechanical and chemical properties following the welding process.

MPW is used by the aerospace, automotive, and nuclear industries.

HYBRID WELDING PROCESSES

Laser beam welding has a number of advantages, such as deeply penetrating welds with a very narrow heat-affected zone. But it does not add filler metal to the weld. Gas metal arc welding has a number of advantages, such as its ability to accurately deliver a wide range of filler metal types to the weld. But it does produce a normal weld width and heat-affected zone.

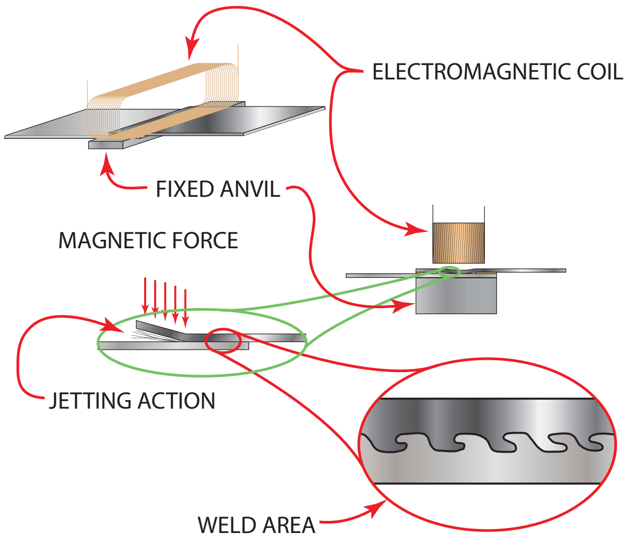


FIGURE 30-61 Magnetic pulse welding.

By combining the two processes, welding engineers have been able to develop a new hybrid process that makes welds that are both narrow and deeply penetrating and have weld buildup, **Figure 30-62**.

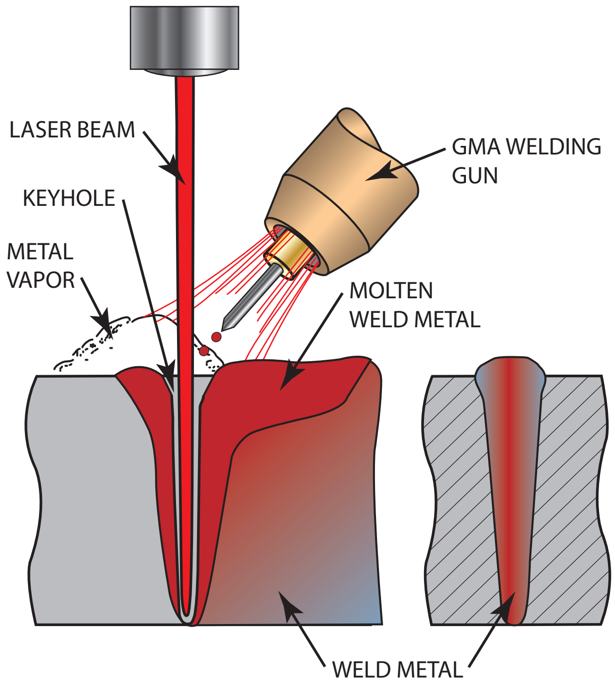


FIGURE 30-62 Hybrid process of laser beam welding and gas metal arc welding.

Summary

Of the nearly 121 welding processes in use today, only a few are commonly used. Often there are processes that, if applied to a weldment, could increase productivity and reduce cost. However, lack of knowledge of the various processes often limits their selections. Understanding the opportunities that are afforded by these various processes will make you far more competitive in the labor market and business world. For example, a company may be using a torch brazing process when a furnace braze may be more effective. Sometimes we become comfortable with our knowledge and abilities with a single process and fail to look at all of the emerging technology's opportunities.

Also, the welding industry is constantly improving existing welding processes and developing new ones. An example of an improvement to an existing welding process is the way laser beam welding and gas metal arc welding have been combined to form a hybrid process. Staying current on new processes and applications is important, and some good sources of current knowledge are welding applications, manufacturers' literature, and the Internet. You should become a member of a professional organization, such as the American Welding Society; this will provide you with up-to-date process information. Learning to weld is a lifelong activity.

Review

1. What protects the molten SAW pool from the atmosphere?
2. How can manual SA welding gun movement be performed?
3. What are the two methods of mechanical travel for SA welding?
4. How is the weld metal deposited in the molten weld pool of the SA welding process?
5. In what forms can SA welding filler metal be purchased?
6. How is the manganese range of the SA electrode noted in the AWS classification?
7. Why could a single SA welding flux have more than one AWS classification?
8. List the three groupings of SA welding fluxes according to their method of manufacturing.

9. Why are alloys not added to fused SA fluxes?
10. What is in bonded SA fluxes?
11. What must be done with SA fluxes to prevent contamination of the weld by hydrogen?
12. Why does the welder not have to wear a welding helmet?
13. What happens to the unfused SA welding flux?
14. Why is some form of mechanical guidance required with SA welding?
15. List the common methods used to start the SA arc.
16. Why would handheld SA welding be used?
17. What special characteristics must ES welding slags have?
18. What heats the ES welding flux?
19. How is an ES weld started?
20. Why do ES welds have large grain sizes?
21. List the advantages of ES welding.
22. What is the major difference between ESW and EGW?
23. What generates the heat for fusion in resistance welding?
24. What can be used to produce the force needed to hold the work together for resistance welds?
25. What are the basic resistance welding processes?
26. What steps can be included in RSW?
27. What are the three types of spot welding machines in common use?
28. What are some of the uses for a portable spot welder?
29. How is seam welding similar to spot welding?
30. What is the most common joint for seam welds?
31. What is RSEW-HF used for?
32. What metals are readily welded by the RPW process?
33. Why is FW not usually cost-effective for short production runs?
34. What is the main difference between upset welding and flash welding?
35. What unusual metal combination can be welded using percussion welding?
36. What are the characteristics of an EB weld?
37. To make an EB weld, what is the least amount of vacuum that a part must be subjected to?
38. How is the beam focus changed in the EB welding process?
39. How can a misaligned seam be tracked automatically for EB welds?
40. What types of welds are most commonly made with the US welding process?
41. What equipment is needed to make US welds?
42. What are the typical applications for US welding?
43. List the steps of the inertia welding process.
44. Referring to Table 30-1, what dissimilar metals can be joined to the metals listed below with inertia welding:
    - **a.** to 1100 or 6061 aluminum?
    - **b.** to pure titanium?
45. What difficult metals can be welded with a laser?
46. How is the plasma arc stiffened?
47. How does stud welding work?
48. Why is THSP known as a cold buildup process?
49. Which thermal spray process can be used to apply ceramics?
50. Why should thermal spray coats be applied as thin coats?
51. What is the advantage of using an inert gas for plasma spraying?
52. What causes the coalescence during a cold weld?
53. Why is thermite welding used so extensively for welding of rail ends?
54. How can rail ends be secured for thermite welding?
55. Why must thermite welding supplies and equipment be kept dry?
56. What types of wear can hardfacing protect against?
57. What base metals are used for most hardfacing alloys?
58. What are the advantages of oxyacetylene flame hardfacing?
59. Why should there be as little dilution as possible of the base metal when hardfacing?
60. How can wear provide a self-sharpening effect on some hardfaced parts?
61. What hardfacing alloy is best applied with the gas tungsten arc welding process?

Section 6

Oxyfuel Processes

Success Story

Jay Jones has been associated with welding as long as he can remember. His father is a mechanical engineer and was also a hot-rodder who exposed Jay to many unique mechanical, machining, and welding opportunities. He said his father's eyes were never very good and remembers at the age of 12 being asked to run a bead on the frame of a hot-rod that his dad was fabricating. From that day on, he claimed to be a "rod burner." He had no formal education but a lot of OJT (on-the-job training).

Starting the eighth grade, Jay was faced with a tough decision that at the time he had no idea would impact the rest of his life. The school offered metal shop for eighth graders, and the previous two years he had taken band. He said, "The rub was that the band class and metal shop were both electives, and I was not allowed to take them both, so I chose 'SHOP!'" He continued his metal shop training in high school and joined an industrial arts club.

Jay took welding classes at college where he learned an array of technologies he never imagined related to welding. While attending college, he purchased the equipment to set up his first welding rig. This allowed him to earn money around his class schedule. His welding instructor said, "I recognized Jay's abilities and passions for welding and was pleased he agreed to be my welding lab assistant." Later, Jay became an adjunct instructor and taught in college for the next 18 years.

In 1981, Jay joined the AWS as a student member, and this was another life changing decision for him because of the people he came to know through the AWS. Many of them were pillars in the welding industry who cared enough to take time with a "punk kid" like himself.

Jay earned his Lifetime Texas Teaching Certificate and taught welding in high school before accepting a job with Victor Equipment Co. in 2000. At Victor he started as the training specialist where he conducted product seminars globally on all types of gas apparatus. He has become one of the leading authorities for gas apparatus and has had responsibilities around the world.

An opportunity opened up for Jay to take a position with Harris Products, a division of The Lincoln Electric Company. His new position requires less traveling which he says has been something he has wanted for some time.

Jay is a graduate of Eastfield College and Texas A&M University, an author, a past chairman of the North Texas Section of the America Welding Society, AWS Board of Directors. He holds degrees in welding technology and education and is a AWS Certified Welding Educator. He received the AWS District Educator Award in 1999–2003 and the National Instructor Award in 2004–2005.

Jay says, "I'm still active in the AWS, enjoy watching students learn, and love to weld."

Chapter 31

Oxyfuel Welding and Cutting Equipment, Setup, and Operation

OBJECTIVES

After completing this chapter, the student should be able to

- describe how to maintain the major components of oxyfuel welding equipment.
- explain the method of testing an oxyfuel system for leaks.
- demonstrate how to set up, light, adjust, extinguish, and disassemble oxyfuel welding equipment safely.
- explain the chemical reaction that takes place in any oxyfuel flame.
- list the major advantages and disadvantages of the different fuel gases.
- demonstrate an ability to choose correct filler metals.
- explain what conditions affect the selection of filler metal.

KEY TERMS

absolute pressure

acetone

acetylene (C_2H_2)

atmospheric pressure

atoms

backfire

Bourdon tube

carbonizing (carburizing)

combination welding and cutting torch

combustion

combustion rate

creep

cutting torches

cylinder pressure

diaphragm

ferrous filler metals

filler metals

flashback

flashback arrestor

gauge pressure

heat energy

hydrocarbons

injector chamber

inner cone

leak-detecting solution

liquefied fuel gases

manifold system

MAPP®

methylacetylene-propadiene (MPS)

mixing chamber

molecules

neutral flame

optical pyrometer

outer envelope

oxidizing flame

oxyfuel gas torch

oxyhydrogen

oxyhydrogen flame
piccolo tube
primary combustion
purged
regulator gauge
regulators
safety disc
safety release valve
seat
secondary combustion
Siamese hose
spark lighter
two-stage regulators
valve packing
working pressure

INTRODUCTION

The general grouping of processes known as oxyfuel consists of a number of separate processes, all of which burn a fuel gas with oxygen. The oxyfuel flame was used for fusion welding as early as the first half of the 1800s when scientists developed the oxyhydrogen torch. Before that time air fuel torches were used, but because the flame was not hot enough they had limited success. The early use of pure oxygen with hydrogen or acetylene as the fuel gas often resulted in flashbacks and explosions. The use of water traps helped prevent most flashbacks from becoming explosions. But until the early development of the torch mixing chamber, welding was a very dangerous occupation. The mixing chamber gave a more uniform flame that was less likely to flash back.

During the early 1900s, the oxyacetylene flame became more popular as the primary means of welding. Since 1900 when the first shielded metal arc welding (stick) electrodes were introduced by Strohmeyer in Britain, the use of the oxyacetylene flame for welding has declined. During oxyacetylene welding's prime, plates 1 in. (25 mm) thick or more were gas welded to build everything from large seagoing ships to massive machines used during the Industrial Revolution. Today, because of improvements in other processes, the oxyacetylene flame is seldom used on metal thicker than 1/16 in. (2 mm).

Oxyfuel welding, cutting, brazing, hardsurfacing, heating, and other processes use the same basic equipment. When storing, handling, assembling, testing, adjusting, lighting, shutting off, and disassembling this basic equipment, the same safety procedures must be followed for each process. Improper or careless work habits can cause serious safety hazards. Proper attention to all details makes these processes safe.

Certain basic equipment is common to all gas welding. Cylinders, regulators, hoses, hose fittings, safety valves, torches, and tips are some of the basic equipment used. Although numerous manufacturers produce a large variety of gas equipment, it all works on the same principle. When welders are not sure how new equipment is operated, they should seek professional help. A welder should never experiment with any equipment.

All oxyfuel processes use a high-heat, high-temperature flame produced by burning a fuel gas mixed with pure oxygen. The gases are supplied in pressurized cylinders. The gas pressure from the cylinder must be reduced by using a regulator. The gas then flows through flexible hoses to the torch. The torch controls this flow and mixes the gases in the proper proportion for good combustion at the end of the tip.

Acetylene is the most widely used fuel gas, but approximately 25 other gases are available. The regulator and tip are usually the only equipment changes required to use another fuel gas. The adjustment and skill required are often different, but the storage, handling, assembling, and testing are the same. When changing gases, make sure the tip can be used safely with the new gas.

The advances in shielded metal arc welding, gas tungsten arc welding, plasma arc cutting, and gas metal arc welding have overshadowed oxyfuel welding. These processes are faster and cleaner and cause less distortion than oxyfuel welding. Currently, oxyfuel welding is used mainly for farm repairs, maintenance, and in smaller shops.

Because of the similarities in the way equipment is operated and assembled, the following information can be easily applied to all oxyfuel welding systems.

PRESSURE REGULATORS

All pressure **regulators** reduce the high cylinder or system pressure to the proper lower working pressure. It is important for the regulator to keep the lower pressure constant over a range of flow rates. Some of the various types of pressure regulators are low-pressure regulators, high-pressure regulators, single-stage regulators, dual-stage regulators, cylinder regulators, manifold regulators, line regulators, and station regulators. Although they all work the same, they are not interchangeable.

CAUTION

Although all regulators work the same way, they cannot be safely used interchangeably on different types of gas or for different pressure ranges without the possibility of a fire or an explosion.

Regulator Operation

A regulator works by holding the forces on both sides of a **diaphragm** in balance, **Figure 31-1**. As the adjusting screw is

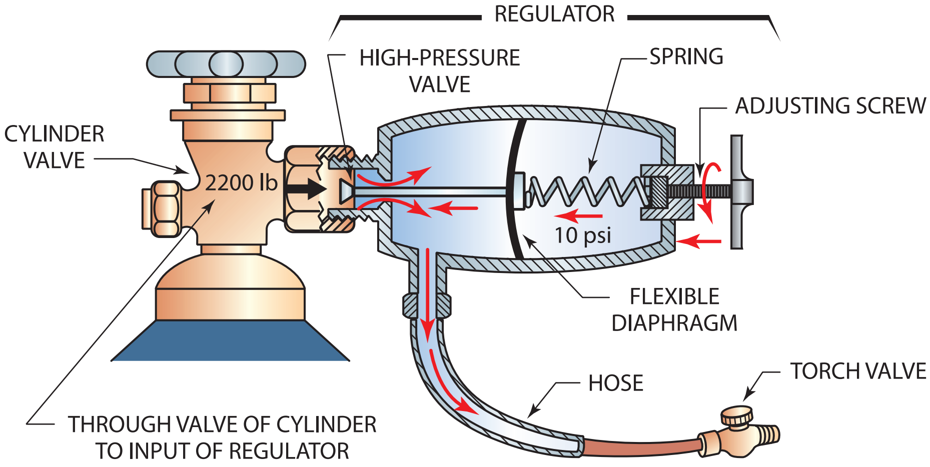


FIGURE 31-1 Force applied to the flexible diaphragm by the adjusting screw through the spring opens the high-pressure valve.

turned inward, it increases the force of a spring on the flexible diaphragm and bends the diaphragm away. As the diaphragm is moved, the small high-pressure valve is opened, allowing more gas to flow into the regulator. The gas pressure cancels the spring pressure, and the diaphragm returns back to its original position, closing the high-pressure valve, **Figure 31-2**. When the regulator is used, the gas pressure on the back side of the diaphragm is reduced, the spring again forces the valve open, and gas flows. The drop in the internal pressure can be seen on the working pressure gauge, **Figure 31-3**.

The size of a regulator determines its ability to hold the working pressure constant over a wider range of flow

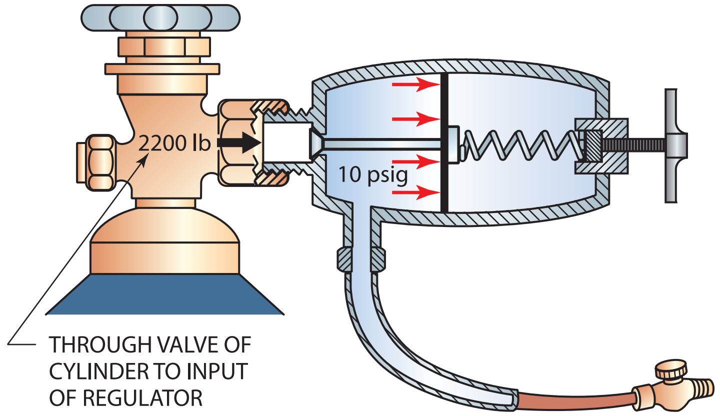


FIGURE 31-2 When the gas pressure against the flexible diaphragm equals the spring pressure, the high-pressure valve closes.

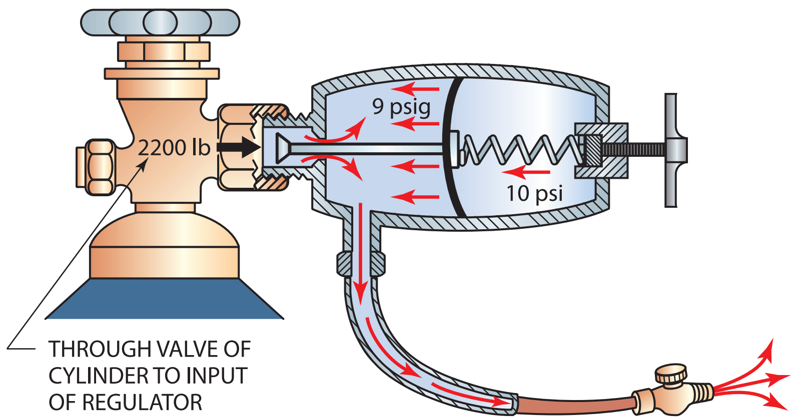


FIGURE 31-3 A drop in the working pressure occurs when the torch valve is opened and gas flows through the regulator at a constant pressure.

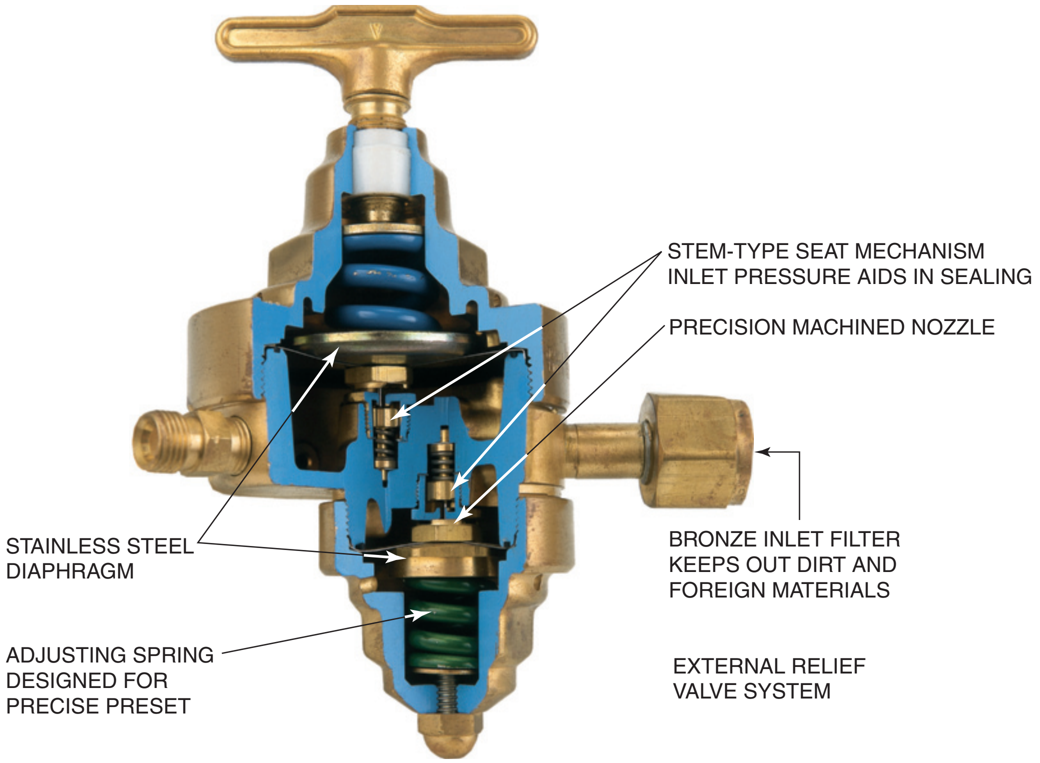


FIGURE 31-4 Two-stage oxygen regulator.

rates. **Two-stage regulators**, **Figure 31-4**, are able to keep the pressure constant at very low or high flow rates as the cylinder empties and its pressure drops. This type of regulator has two sets of springs, diaphragms, and valves. The first spring is preset at the factory to reduce the cylinder pressure to 225 psig (1550 kPag). The second spring is adjusted like other regulators. Because the second high-pressure valve has to control a maximum pressure of only approximately 225 psig (1550 kPag), it can be larger, thus allowing a greater flow.

Regulator Gauges

There may be one or two pressure gauges on a regulator. One pressure gauge shows the working pressure, and the other indicates the cylinder pressure, **Figure 31-5**. The

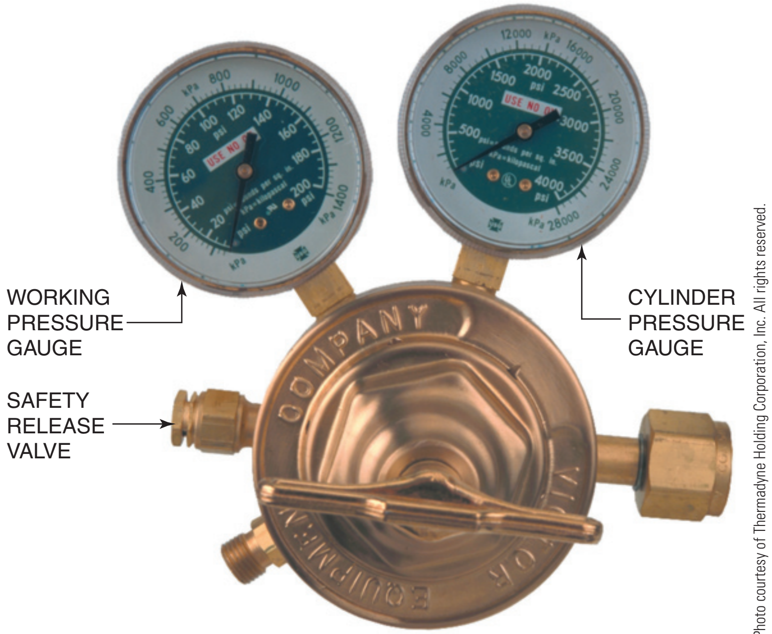


FIGURE 31-5 Safety release valve on an oxygen regulator.

Tip Pressure psig (kg/cm² G)	Regulator Pressure* for Hose Lengths ft (m)				
	10 ft (3 m)	25 ft (7.6 m)	50 ft (15.2 m)	75 ft (22.9 m)	100 ft (30.5 m)
1 (0.1)	1 (0.1)	2.25 (0.15)	3.5 (0.27)	4.75 (0.35)	6 (0.4)
5 (0.35)	5 (0.35)	6.25 (0.4)	7.5 (0.52)	8.75 (0.6)	10 (0.7)
10 (0.7)	10 (0.7)	11.25 (0.75)	12.5 (0.85)	13.75 (0.95)	15 (1.0)

*These values are for hose with a diameter of 1/4 in. (6 mm); larger or smaller hose diameters or high flow rates will change these pressures.

TABLE 31-1 Regulator Pressure for Various Lengths of Hose

working pressure gauge shows the pressure at the regulator and not at the torch. The pressure at the torch is always less than the pressure shown on the working pressure gauge. This pressure difference results from the resistance to the gas flow, which is referred to as line pressure drop. The smaller in diameter or longer a line is, the greater the pressure drop will be, **Table 31-1**.

EXPERIMENT 31-1

Line Resistance

In this experiment, two pieces of the same diameter hose are required. One piece of hose is to be a short length, less than 10 ft (3 m) long. The other piece of hose is to be more than 25 ft (8 m) long. Blow through the short piece and then blow through the long piece. Observe the difference.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor.

The high-pressure gauge on a regulator shows **cylinder pressure** only. This gauge is used to indicate the amount of gas that remains in a cylinder. However, cylinders containing liquefied gases, such as CO_2, propane, and MPS, must be weighed to determine the amount of gas remaining.

Inside a **regulator gauge** there is a **Bourdon tube**. This tube is bent in the shape of the letter *C*, with one end attached solidly to the gauge body and the other end attached through a gear to a needle, **Figure 31-6**. As the pressure inside the tube increases, the tube tries to straighten out.

The pressure shown on a gauge is read as pounds per square inch gauge (psig) or kilopascals (kPag). The **atmospheric pressure**, 14.7 psi (101.35 kPa), must be added to the **gauge pressure** to find the **absolute pressure**, psia (kPaa). In welding, psig and psi (kPag and kPa) are used interchangeably. ◆

REGULATOR SAFETY PRESSURE RELEASE DEVICE

Regulators may be equipped with either a **safety release valve** or a **safety disc** to prevent excessively high pressures from damaging the regulator. A safety release valve is made

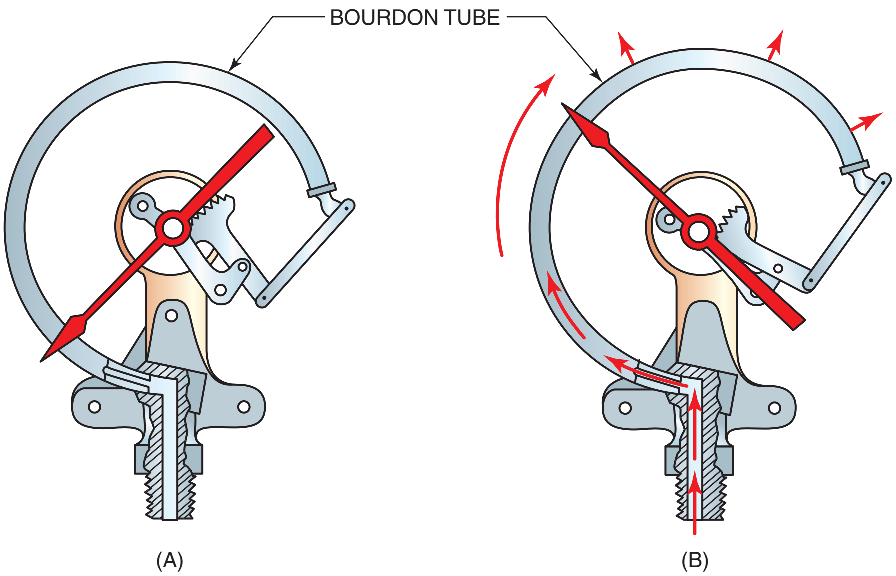


FIGURE 31-6 Gauge before pressure is applied (A) and gauge after pressure is applied (B).

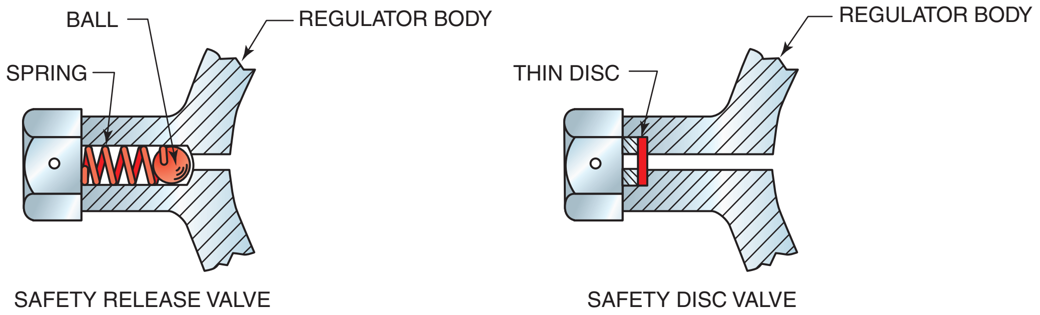


FIGURE 31-7 Pressure release valves.

up of a small ball held tightly against a **seat** by a spring. The release valve will reseat itself after the excessive pressure has been released.

A safety disc is a thin piece of metal held between two seals, **Figure 31-7**. When a safety disc bursts to release excessive pressure, all of the gas in the cylinder will be released. A safety disc does not reseal, so it must be replaced before the regulator can be used again.

Cylinder and Regulator Fittings

A variety of inlet or cylinder fittings are available to ensure that the regulator cannot be connected to the wrong gas or pressure, **Figure 31-8A** through **D**. A few adapters are available that will allow some regulators to be attached to a different type of fitting. The following are the two most common types: (1) adapt a left-hand male acetylene cylinder fitting to a right-hand female regulator fitting, or vice versa, and (2) adapt an argon or mixed gas male fitting to a female flat washer-type CO_2 fitting, **Figure 31-9**.

Cryogenic Cylinders

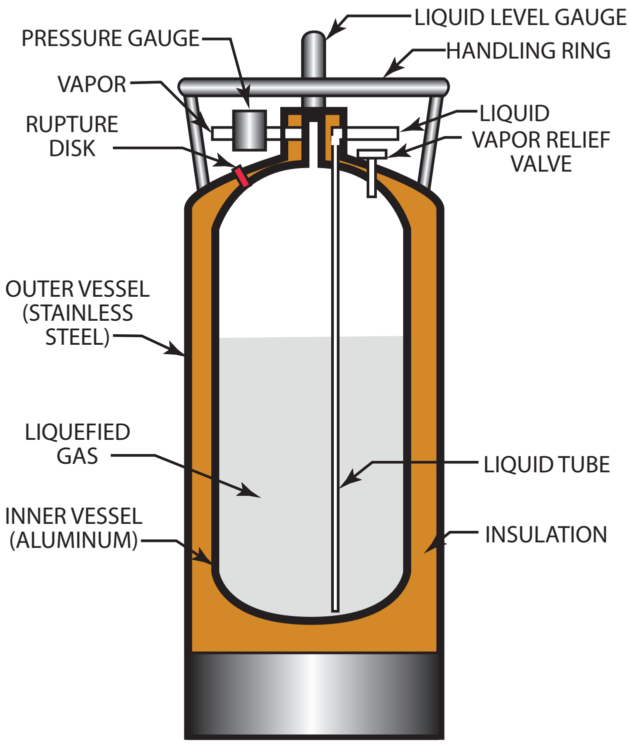
Some gasses can be supplied as extremely cold liquids in cryogenic cylinders. Cryogenic liquids have a boiling point below −238°F (−150°C). The most commonly used

FIGURE 31-8 (A) Acetylene cylinder valve (left-hand thread). (B) Oxygen cylinder valve. (C) Argon cylinder valve. (D) Carbon dioxide (CO_2) cylinder valve.

(A)

(B)

FIGURE 31-9 (A) Acetylene cylinder adapter. (B) Carbon dioxide-to-argon adapter.



CRYOGENIC LIQUID CYLINDER

FIGURE 31-10 Cryogenic cylinder.

cryogenic liquid gases in welding are oxygen, argon, and nitrogen. The advantage of using cryogenic gasses is that one cryogenic cylinder can replace a lot of standard compressed gas cylinders. In high-volume shops cryogenic cylinders can be a great labor-saving and space-saving addition.

To maintain oxygen and other gases as a liquid, they must be kept at a cryogenic temperature so the cylinder pressure can be kept below 300 psig (2.07 MPa). If the liquid is allowed to warm up, then the pressure in the cylinder would cause it to explode. To help maintain these very low temperatures, cryogenic cylinders are constructed like giant vacuum thermos bottles, **Figure 31-10**. The process of converting the liquid to a gas causes the liquid to stay very cold. To maintain the liquid's cryogenic temperature, some gas may be vented automatically from the cylinder if the gas is not being drawn off for use in the shop. This venting is normal.

Cryogenic cylinders have connections so that either liquid or vapor can be drawn out of the cylinder.

CAUTION

Cryogenic liquids are very dangerous; improper handling of these liquids can cause serious injury or death. Never connect, disconnect, or work on a cryogenic cylinder without first being properly trained.

Fittings

The connections to the cylinder and to the hose must be kept free of dirt and oil. Fittings should screw together freely by hand and require only light wrench pressure to be leak-tight. If the fitting does not tighten freely on the connection, then both parts should be cleaned. If the joint leaks after it has been tightened with a wrench, then the seat should be checked. Examine the seat and threads for damage. If the seat is damaged, it can be repaired by a manufacturer-authorized regulator repair shop. Severely damaged connections must be replaced.

REGULATOR SAFETY PRECAUTIONS

The regulator pressure-adjusting screw should be backed off each time the oxyfuel system is being shut down. This is done to release the spring and diaphragm pressures, which,

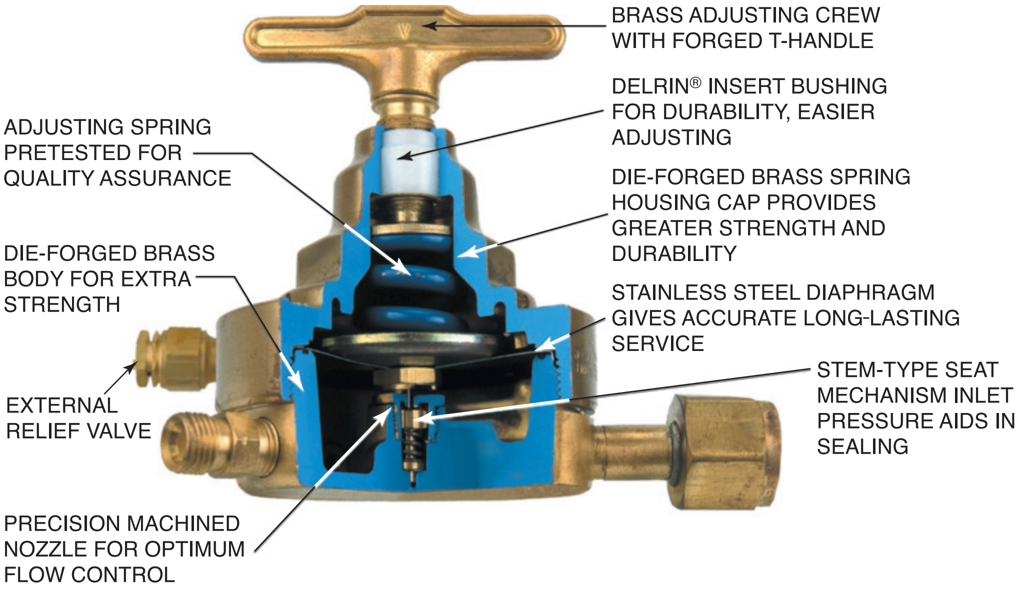


FIGURE 31-11 Single-stage oxygen regulator.

over time, may cause damage. Keeping a spring compressed and the diaphragm stretched can cause the spring to weaken and the diaphragm to be permanently distorted.

In addition, when the cylinder valve is reopened, some high-pressure gas can pass by the open high-pressure valve before the diaphragm can close it. This condition may cause the diaphragm to rupture or the low-pressure gauge to explode, or both.

High-pressure valve seats that leak result in a **creep** or rising pressure on the working side of the regulator. This usually occurs when the gas pressure is set but no gas is flowing. If the leakage at the seat is severe, then the maximum safe pressure can be exceeded on the working side, resulting in damage to the diaphragm, gauge, hoses, or other equipment.

CAUTION

Regulators that creep excessively or beyond the safe working pressure must not be used.

A diaphragm can be tested for leaks by first setting the regulator to 14 psig (95 kPag) for fuel gases or 45 psig (310 kPag) for oxygen and other gases. Once the pressure is set, place a finger over the vent hole and spray it with a **leak-detecting solution**, **Figure 31-11**. Slowly move the finger from the hole and watch for bubbles, which indicate a leak.

A gauge that gives a faulty reading or that is damaged can result in dangerous pressure settings. Gauges that do not read "0" (zero) pressure when the pressure is released, or those that have damaged glass or case, must be repaired or replaced.

CAUTION

All work on regulators must be done by properly trained repair technicians.

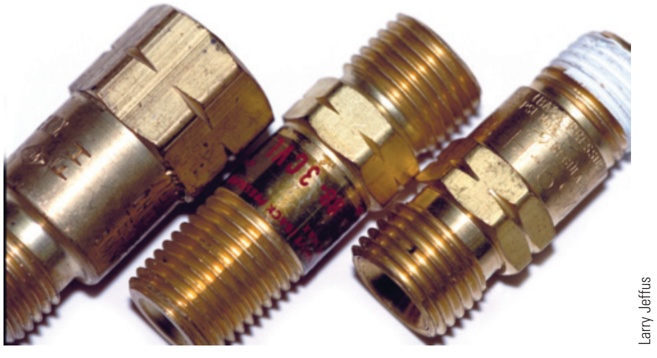


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FIGURE 31-12 Left-hand threaded fittings are identified with a notch.

CAUTION

Regulators should be located far enough from the actual work that flames or sparks cannot reach them.

The outlet connection on a regulator is either a right-hand fitting for oxygen or a left-hand fitting for fuel gases. A left-hand threaded fitting has a notched nut, **Figure 31-12**.

REGULATOR CARE AND USE

There are no internal or external moving parts on a regulator or a gauge that require oiling, **Figure 31-13**.

CAUTION

Oiling a regulator is unsafe and may cause a fire or an explosion.

FIGURE 31-13 Never oil a regulator.

FIGURE 31-16 A combination welding and cutting torch kit.

If the adjusting screw becomes tight and difficult to turn, then it can be removed and cleaned with a dry, oil-free rag. When replacing the adjusting screw, be sure it does not become cross-threaded. Many regulators use a nylon nut in the regulator body, and the nylon is easily cross-threaded.

When welding is finished and the cylinders are turned off, the gas pressure must be released and the adjusting screw backed out. This is required both by federal regulation and to prevent damage to the diaphragm, gauges, and adjusting spring if they are left under a load. A regulator that is left pressurized causes the diaphragm to stretch, the Bourdon tube to straighten, and the adjusting spring to compress. These changes result in a less accurate regulator with a shorter life expectancy.

WELDING AND CUTTING TORCHES: DESIGN AND SERVICE

The oxyacetylene hand torch is the most common type of **oxyfuel gas torch** used in industry. The hand torch may be either a combination welding and cutting torch or a cutting torch only, **Figure 31-14** and **Figure 31-15**.

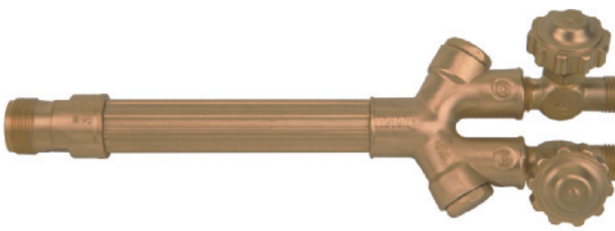

FIGURE 31-14 A torch body or handle used for welding or cutting.

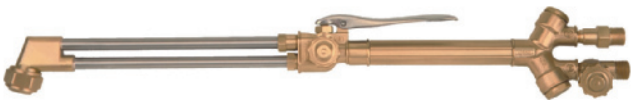

FIGURE 31-15 A torch used for cutting only.

Combination Torches

The **combination welding and cutting torch** offers more flexibility because a cutting head, welding tip, or heating tip can be attached quickly to the same torch body, **Figure 31-16**. Combination torch sets are often used in schools, automotive repair shops, auto body shops, small welding shops, or any other situation in which flexibility is needed. The combination torch sets usually are more practical for portable welding because the one unit can be used for both cutting and welding.

Dedicated Cutting Torches

Dedicated or straight **cutting torches** are usually longer than combination torches. The longer length helps keep the operator farther away from heat and sparks. In addition, thicker material can be cut with greater comfort.

Most manufacturers make torches in a variety of sizes for different types of work. There are small torches for jewelry work, **Figure 31-17**, and large torches for heavy plates. Specialty torches for heating, brazing, or soldering are also available. Some of these use a fuel-air mixture, **Figure 31-18**. Fuel-air torches are often used by plumbers and air-conditioning technicians for brazing and soldering copper pipe and tubing. There are no industrial standards for tip size identification, tip threads, or seats. Therefore, each style, size, and type of torch can be used only with the tips made by the same manufacturer to fit the specific torch.

FIGURE 31-17 Medium-duty torch for smaller jobs.

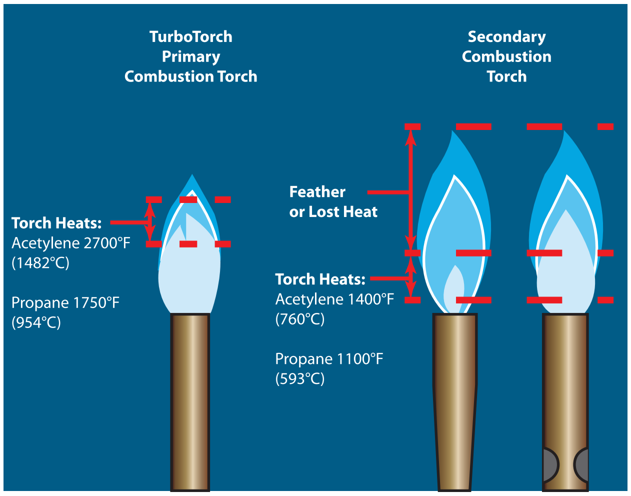

FIGURE 31-18 Some air/gas torches use a special tip that improves the combustion for a hotter, more effective flame.

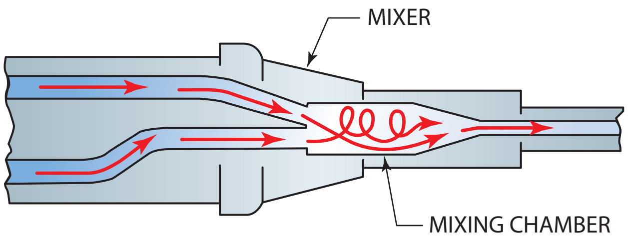

FIGURE 31-20 Equal-pressure mixing chamber.

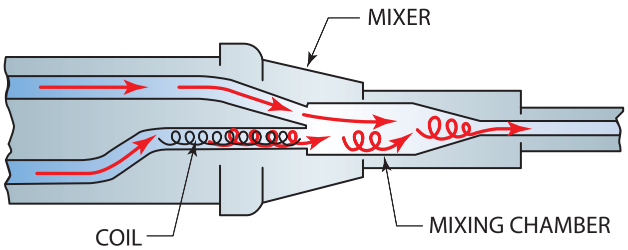

FIGURE 31-21 A metal coil in the oxygen tube spins the gas, ensuring a complete mixing of gases.

MIXING THE GASES

Two basic methods are used for mixing the oxygen and fuel gas to form a hot, uniform flame. The two gases must be mixed completely before they leave the tip and create the flame. If the gases are not mixed completely, then the torch will have a greater tendency to backfire or flash back. One method uses equal or balanced pressures, and the gases are mixed in a **mixing chamber**. The other method uses higher oxygen pressure, and the gases are mixed in an **injector chamber**.

Mixing Chamber

The mixing chamber of the equal-pressure torch may be located in the torch body, attached to the tip, or in the tip, **Figure 31-19**. Both gases must enter the enlarged mixing chamber through small, separate openings. Because the mixing chamber is larger than the total size of both entrance holes and the exit hole, the gases experience a rapid drop in pressure as they enter the chamber. The rapid drop in pressure causes the gases to become turbulent and mix thoroughly, **Figure 31-20**. Some manufacturers spin the gases before they enter the chamber to ensure complete mixing, **Figure 31-21**.

Injector Mixing

The injector torches work both with equal gas pressures or low fuel-gas pressures, **Figure 31-22**. The injector allows oxygen at the higher pressure to draw the fuel gas into the chamber, even when the fuel-gas pressure is as low as 6 oz/in.^{2} (26.3 g/cm^2). The injector works by passing the oxygen through a venturi, which creates a vacuum to pull the fuel gas in and then mixes the gases together. An injector-type torch must be used if a low-pressure acetylene generator or low-pressure residential natural gas is used as a fuel-gas supply.

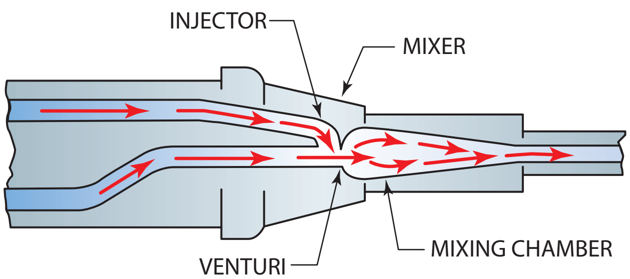

FIGURE 31-22 Injector mixing system.

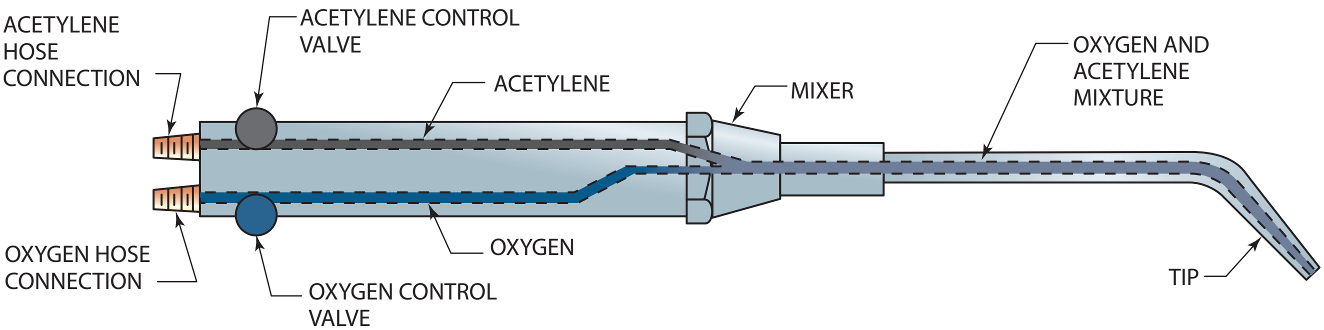

FIGURE 31-19 Schematic drawing of an oxyacetylene welding torch.

TORCH CARE AND USE

The torch body contains threaded connections for the hoses and tips. These connections must be protected from any damage. Most torch connections are external and made of soft brass that is easily damaged. Some connections, however, are more protected because they have either internal threads or stainless steel threads for the tips. The best protection against damage and dirt is to leave the tip and hoses connected when the torch is not in use.

Because the hose connections are close to each other, a wrench should never be used on one nut unless the other connection is protected with a hose fitting nut, **Figure 31-23**.

The hose connections should not leak after they are tightened with a wrench. If leaks are present, then the seat should be repaired or replaced. Some torches have removable hose connection fittings so that replacement is possible.

The valves should be easily turned on and off and should stop all gas flowing with minimum finger pressure. To find leaking valve seats, set the regulators to a working pressure. With the torch valves off, spray the tip with a leak-detecting solution. The presence of bubbles indicates a leaking valve seat, **Figure 31-24**. The gas should not leak past the valve stem packing when the valve is open or when it is closed. To test leaks around the valve stem, set the regulator to a working pressure. With the valves off, spray the valve stem with a leak-detecting solution and watch for bubbles, indicating a leaking **valve packing**. The valve stem packing can now be tested with the valve open. Place a finger over the hole in the tip and open the valve. Spray the stem and watch for bubbles, which would indicate a leaking valve packing, **Figure 31-25**. If either test indicates a leak, then the valve stem packing nut can be tightened until the leak stops. After the leak stops, turn the valve knob. It should still turn freely. If it does not, or if the leak cannot be stopped, replace the valve packing.

The valve packing and valve seat can be easily repaired on most torches by following the instructions given in the repair kit. On some torches, the entire valve assembly can be replaced, if necessary.

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FIGURE 31-23 One hose-fitting nut will protect the threads when the other nut is loosened or tightened.

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FIGURE 31-24 Check all connections for possible leaks and tighten if necessary.

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FIGURE 31-25 The torch valves should be checked for leaks and the valve packing nut should be tightened if necessary.

WELDING AND HEATING TORCH TIPS

Because no industrial standard tip size identification system exists, the student must become familiar with the size of the orifice (hole) in the tip and the thickness range for which it can be used. Comparing the overall size of the tip can be done only for tips made by the same manufacturer for the same type and style of torch, **Figure 31-26**. Learning a specific manufacturer's system is not always the answer because on older, worn tips the orifice may have been enlarged by repeated cleaning.

Tip sizes can be compared to the numbered drill bit size used to make the hole, **Table 31-2**. The sizes of tip cleaners are given according to the drill bit size of the hole they fit. By knowing the tip cleaner size commonly used to clean a tip, the welder can find the same size tip made by a different manufacturer. The tip size can also be determined by trial and error.

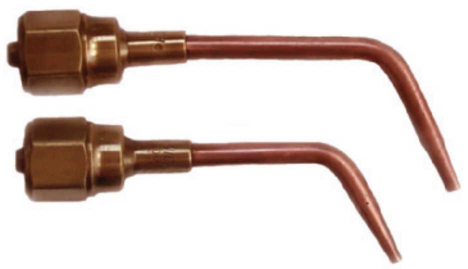

Photo courtesy of Thermadyne Holding Corporation, Inc. All rights reserved.

FIGURE 31-26 A variety of tip sizes are available for each torch body.

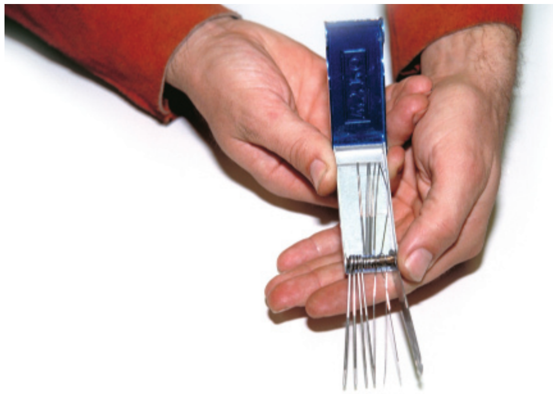

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FIGURE 31-27 Standard set of tip cleaners.

Tip Cleaner Standard Set			
	Use Cleaner	For Drill	
			77 = 0.0160″
Smallest	1	77-76	(0.4064 mm)
	2	75-74	
	3	73-72-71	
	4	70-69-68	
	5	67-66-65	
	6	64-63-62	
	7	61-60	
	8	59-58	
	9	57	
	10	56	
	11	55-54	
	12	53-52	49 = 0.0730″
Largest	13	51-50-49	(1.8542 mm)

TABLE 31-2 Tip Cleaner Size Compared to Drill Size Found on Most Standard Tip-Cleaning Sets

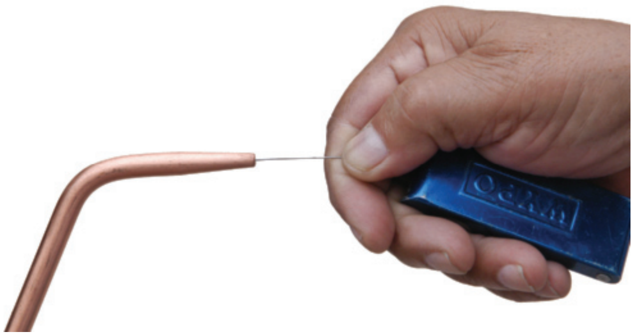

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FIGURE 31-28 Cleaning a tip with a standard tip cleaner.

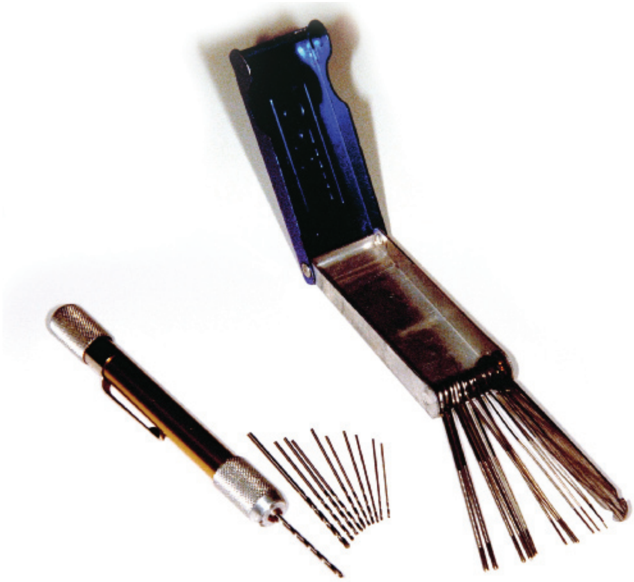

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FIGURE 31-29 Tools used to repair tips.

On some torch sets, each tip has its own mixing chamber. On other torch sets, however, one mixing chamber may be used with a variety of tip sizes.

Torch Tip Care and Use

Torch tips may have metal-to-metal seals, or they may have an O-ring or a gasket between the tip and the torch seat. Metal-to-metal seal tips must be tightened with a wrench. Tips with an O-ring or a gasket may be tightened by hand. Using the wrong method of tightening the tip fitting may result in damage to the torch body or the tip.

Dirty tips can be cleaned using a set of tip cleaners. Using the file provided in the tip-cleaning set, **Figure 31-27**, file the end of the tip smooth and square. Next, select the size of tip cleaner that fits easily into the orifice. The tip cleaner is a small, round file and should be moved in and out of the orifice only a few times, **Figure 31-28**. Be sure the tip cleaner is straight and that it is held steady to prevent it from bending or breaking off in the tip. Excessive use of the tip cleaner tends to ream the orifice, making it too large. Therefore, use the tip cleaner only as required. Once the tip is cleaned, turn on the oxygen for a moment to blow out any material loosened during the cleaning.

Damaged tips or tips with cleaners broken in them can be reconditioned, but they require a good deal of work and some specialized tools, **Figure 31-29**.

BACKFIRES AND FLASHBACKS

Backfires

A backfire occurs when a flame goes out with a loud snap or pop. A backfire may be caused by one or more of the following:

- Touching the tip against the workpiece
- Overheating the tip
- Operating the torch when the flame settings are too low
- Loose tip
- Damaged seats
- Dirt in the tip

The problem that caused the backfire must be corrected before relighting the torch. A backfire may cause a flashback.

Flashbacks

When a flashback occurs, the flame is burning back inside the tip, torch, hose, or regulator. A flashback produces a high-pitched whistle. If the torch does flash back, close the oxygen valve at once and then close the fuel valve. The order in which the valves are closed is not as important as the speed at which they are closed. A flashback that reaches the cylinder may cause a fire or an explosion.

Closing the oxygen valve on the torch stops the flame inside at once. Then, the fuel-gas valve should be closed and the torch should be allowed to cool off before repairing the problem. When a flashback occurs, there is usually a serious problem with the equipment, and a qualified technician should be called. After locating and repairing the problem, blow gas through the tip for a few seconds to clear out any soot that may have accumulated in the passages. A flashback that burns in the hose leaves a carbon char inside that may explode and burn in a pressurized oxygen system. A fuel gas is not required to kindle a hot, severe fire inside such hose sections. Discard hose sections in which a flashback has occurred and obtain new hose.

REVERSE FLOW AND FLASHBACK VALVES

The purpose of the reverse flow valve is to prevent gases from accidentally flowing through the torch and into the wrong hose. If the gases being used are allowed to mix in the hose or regulator, they might explode. The reverse flow valve is a spring-loaded check valve that closes when gas tries to flow backward through the torch valves, **Figure 31-30**. Most torches have reverse flow valves built into the torch body, but some torches must have these safety devices added. If the torch does not come with a reverse flow valve, then it must be added to either the torch end or regulator end of the hose.

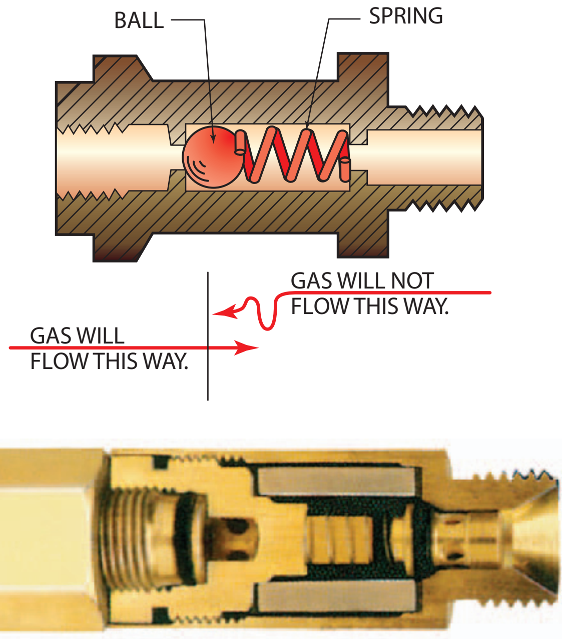


FIGURE 31-30 Reverse flow valve only.

A reverse flow of gas will occur if the torch is not turned off or bled properly. The torch valves must be opened one at a time so that the gas pressure in that hose will be vented into the atmosphere and not through the torch into the other hose, **Figure 31-31**.

> **CAUTION**
>
> If both valves are opened at the same time, one gas may be pushed back up the hose of the other gas.

A reverse flow valve will not stop the flame from a flashback from continuing through the hoses. A **flashback arrestor** will do the job of a reverse flow valve, and it will also stop the flame of a flashback, **Figure 31-32**. The flashback arrestor is designed to quickly stop the flow of gas during a flashback. These valves work on a similar principle as the gas valve at a service station. They are very sensitive to any back pressure in the hose and stop the flow if any back pressure is detected.

Care of the Reverse Flow Valve and Flashback Arrestor

Both devices must be checked on a regular basis to see if they are working correctly. The internal valves may become plugged with dirt, or they may become sticky and not operate correctly. To test the reverse flow valve, you can try to blow air backward through the valve. To test the flashback arrestor, follow the manufacturer's recommended procedure. If the safety device does not function correctly, then it must be replaced.

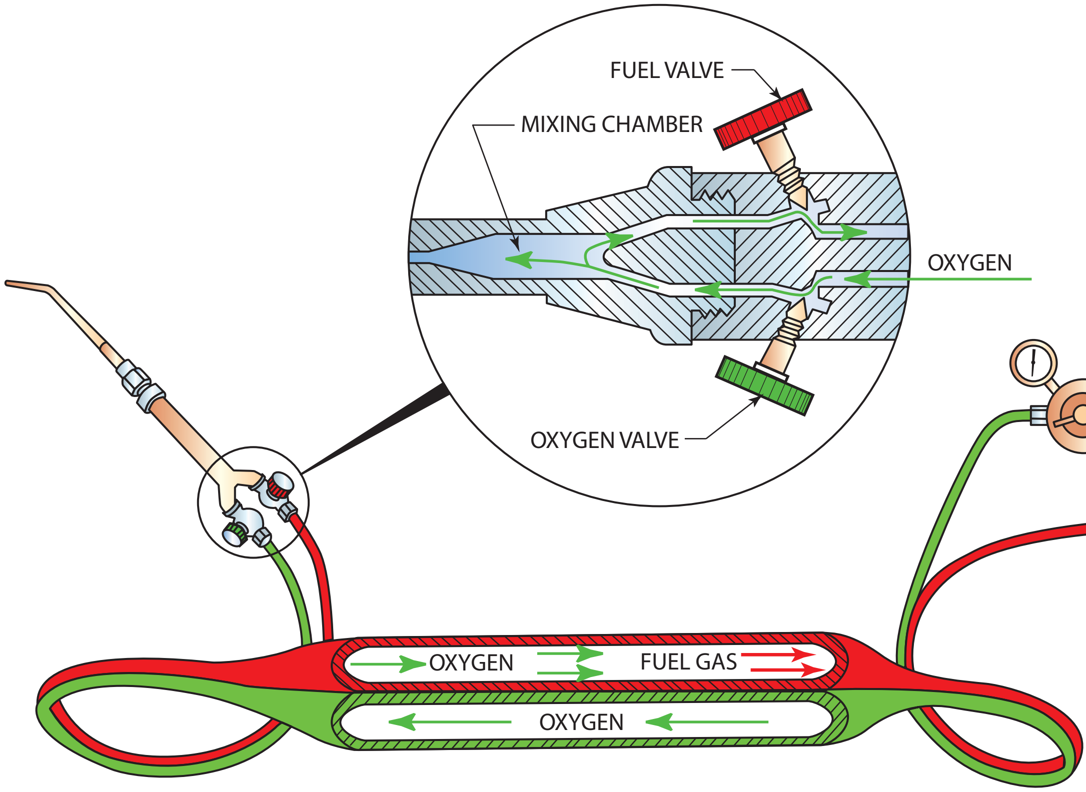


FIGURE 31-31 Gas may flow back up the hose if both valves are opened at the same time when the system is being bled down after use. Installing reverse flow valves on the torch can prevent this from occurring.

FIGURE 31-32 Combination flashback arrestors and check valves for (A) acetylene and (B) oxygen. (C) Replacement cartridge for flashback arrestor. (D) Torch designed with replaceable flashback arrestors and check valves built into the torch body.

HOSES AND FITTINGS

Most welding hoses used today are molded together as one piece and are referred to as **Siamese hose**. Hoses that are not of the Siamese type, or hose ends that have separated, may be taped together. When taping the hoses, they must not be taped solidly. They should be wrapped for approximately 2 in. (51 mm) out of every 12 in. (305 mm) of hose length, allowing the colors of the hose to be seen.

Fuel-gas hoses must be red and have left-hand threaded fittings. Oxygen hoses must be green and have right-hand threaded fittings.

Hoses are available in four sizes: 3/16 in. (4.8 mm), 1/4 in. (6 mm), 5/16 in. (8 mm), and 3/8 in. (10 mm). The size given is the inside diameter of the hose. Larger sizes offer less resistance to gas flow and should be used where long hose lengths are required. The smaller sizes are more flexible and easier to handle for detailed work.

The three sizes of hose end fittings available are A (small), B (standard), and C (large). The three sizes are made to fit all hose sizes.

Hose Care and Use

When hoses are not in use, the gas must be turned off and the pressure bled off. Turning off the equipment and releasing the pressure prevents any undetected leaks from causing a fire or an explosion. This action also eliminates a dangerous situation that would be created if a hose were cut by equipment or materials being handled by workers who were unfamiliar with welding equipment. In addition, hoses are permeable to gases (ability of the gas to pass into or through the hose walls). Thus, gases left under pressure for long periods of time can migrate through the hose walls and mix with each other, **Figure 31-33**. If the gases mix and the torch is lit without first purging the lines, then the hoses can explode. For this reason, if the welder is not certain that the hoses were bled, then it is recommended that they be purged before the torch is lit.

Hoses are resistant to burns, but they are not burnproof. They should be kept out of direct flame, sparks, and hot metal. You must be especially cautious when using a cutting torch. If it becomes damaged, then the damaged section should be removed and the hose should be repaired with a splice. Damaged hoses should never be taped to stop leaks.

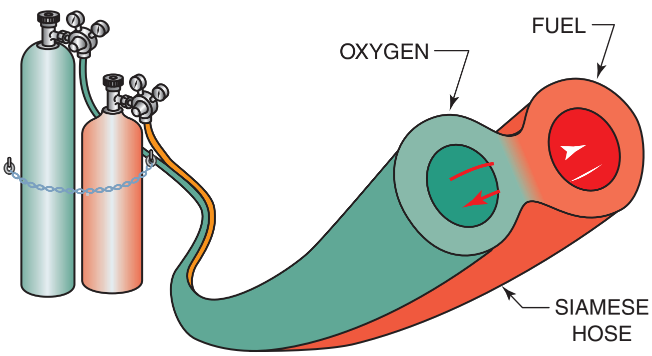


FIGURE 31-33 Gas left under pressure may migrate through the hose walls.

Leak Detection Hoses

Hoses should be checked periodically for leaks. To test a hose for leaks, adjust the regulator to a working pressure with the torch valves closed. Wet the hose with a leak-detecting solution by rubbing it with a wet rag, spraying it, or dipping it in a bucket. Then, watch for bubbles, which indicate that the hose leaks.

The hose fittings can be changed if the old ones become damaged. Several kits are available that have new nuts, nipples, ferrules, a ferrule crimping tool, and any other supplies required to replace the hose ends, **Figure 31-34**.

To replace the hose end, the hose is first cut square. The correct-size ferrule is inserted. Then, both the hose end and nipple are sprayed with a leak-detecting solution. This will help the nipple slide in more easily. Screw the nipple and nut on a torch body. This will hold the nipple deep inside the nut, and the body will act as a handle for leverage as the nipple is pushed inside the hose, **Figure 31-35**. After the hose is slid up to the nut, crimp the ferrule until it is tight. The crimping tool should be squeezed twice, the second time at right angles to the first, **Figure 31-36**. When the crimping is complete, install the hose on a torch and regulator. Then, adjust the regulator to a working pressure and spray the fitting with a leak-detecting solution. Watch for any bubbles, which indicate a leaking fitting.

FIGURE 31-34 Hose repair kit.

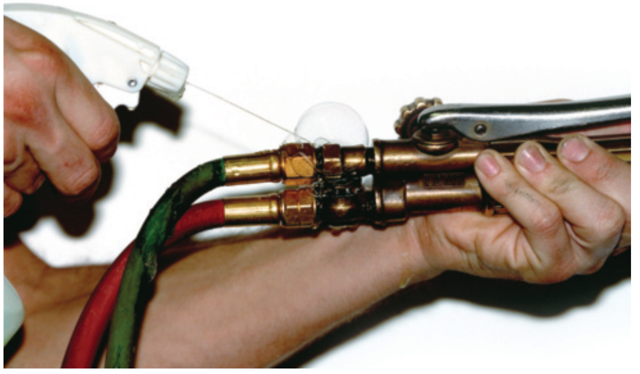
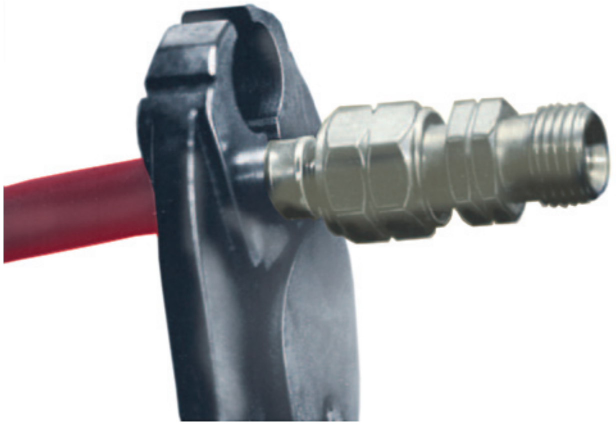


FIGURE 31-35 Screwing the hose nut onto a fitting will help when pushing the nipple into the hose.



Larry Jeffus

FIGURE 31-36 Crimping hose ferrule.

Leak Detection Fittings

A leak-detecting solution can be purchased premixed and ready to use or as a concentrate that must be mixed with water. A leak-detecting solution must be free-flowing so that it can seep into small joints, cracks, and other areas that may have a leak. The solution must produce a good quantity of bubbles without leaving a film. The solution can be dipped, sprayed, or brushed on the joints.

CAUTION

Some detergents are not suitable for O_2 because of an oil base. Use only O_2-approved leak-detection solutions on oxygen fittings.

MANIFOLD SYSTEMS

A **manifold system** can be used if there are a number of workstations or if a high volume of gas will be used. The manifold can also be used to keep the cylinders out of the work area and to reduce the number of cylinders needed at one time.

Courtesy of Cooper Crouse-Hinds®.

FIGURE 31-37 Explosion-proof light fixtures suitable for a manifold room.

Manifolds must be located 20 ft (6 m) or more from the actual work, or they must be located so that sparks cannot reach them. Oxygen manifolds must be at least 20 ft (6 m) from fuel-gas manifolds and flammable materials or must be separated from them by a noncombustible wall 5 ft (1.5 m) high, with a half-hour, fire-resistant rating. Inert gas manifolds can be placed with either oxygen or fuel-gas manifolds.

The rooms that are used for manifolds can also be used for cylinder storage, but full and empty cylinders must be kept separated within the room. Fuel-gas manifold rooms must have good ventilation and explosion-proof lights, **Figure 31-37**. They must also have a sign on the door that reads "Danger: No Smoking, Matches, or Open Lights," or similar wording.

Piping for the high-pressure side of a manifold must be steel, stainless steel, or alloyed copper. Piping for the low-pressure side, except acetylene, can be stainless steel, copper (type L or K), brass, steel, or wrought iron. All acetylene piping must be steel or wrought iron. Unalloyed copper used with acetylene forms an unstable and explosive compound, copper acetylide.

The pipe joints in copper or brass lines can be welded, brazed, threaded, or flanged. Joints in steel or iron pipe can be welded, threaded, or flanged. Nitrogen should be purged through pipes being welded or brazed. All piping must be clean and oil-free and should have a slight angle back toward the manifold so that any moisture will run back toward it, **Figure 31-38**.

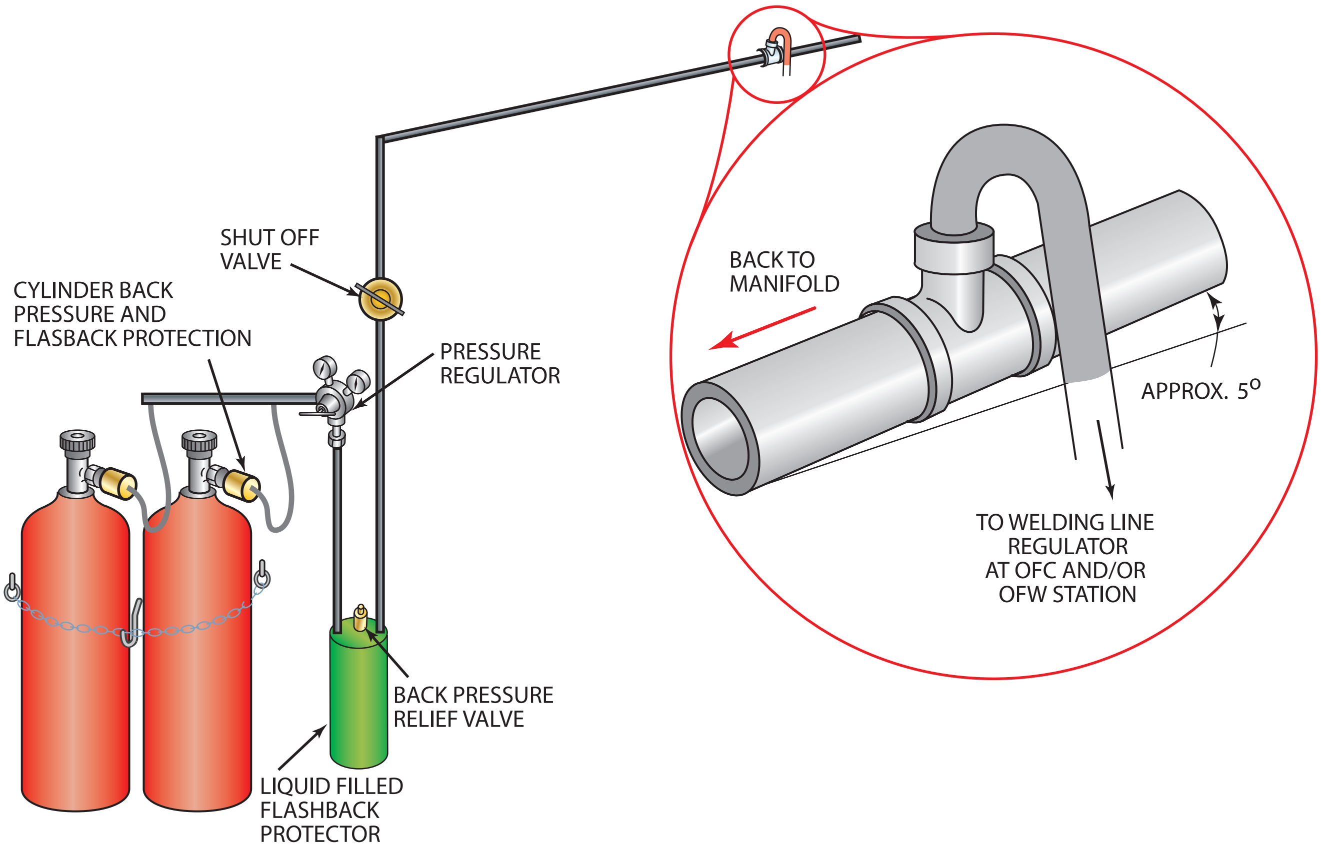


FIGURE 31-38 Typical manifold system.

Manifold systems should be tested for leaks at one and one-half (1 1/2) times the operating pressure. The fuel-gas lines must be protected from oxygen flowing back into the lines by installing a reverse flow valve. In addition, fuel-gas lines must have flashback protection and back pressure release. One device can be installed to satisfy all three requirements, Figure 31-38.

Manifold Operation

The pipes should be cleaned with an oil-free, noncombustible fluid before the regulators are attached. Solutions of caustic soda or trisodium phosphate are good for this purpose. Once the system is cleaned, install the regulators and purge the system with nitrogen. Nitrogen will pick up any moisture in the system while providing a noncombustible gas in the system.

After the system has been filled with nitrogen, start filling the pipes with the oxygen or fuel gas. Allow the gas to escape freely from the station farthest away from the manifold. Continue purging until all the nitrogen is removed from the manifold.

CAUTION

Make sure there is good ventilation during the purging and that there are no sources of ignition near the escaping gas.

Set the line pressure as low as possible, still ensuring that the type of work being done at the workstations can be performed satisfactorily, **Figure 31-39**. When work is completed, the system must be turned off and each station, manifold, and cylinder valve must be closed. If a station regulator is removed, a cap must be put on the line so that air cannot enter the system, **Figure 31-40**. A complete list of operating, maintenance, and emergency procedures should be clearly posted for all manifolds.

FIGURE 31-39 Label on gauge notes the maximum pressure to be used.

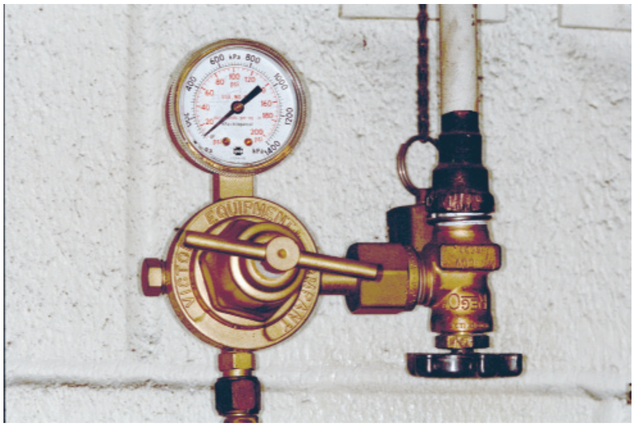


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FIGURE 31-40 Manifold station regulators.

CAUTION

In case of fire or severe threatening weather, such as a tornado, all cylinder valves must be turned off.

OXYFUEL FLAME

In the late 1880s, an oxyfuel flame was first used to melt through thin metal. In approximately 1900, the oxygen lance was introduced. The oxygen lance allowed high-pressure oxygen to be directed onto metal heated by a torch, resulting in much improved cuts. The later development of a cutting torch with preheating flames surrounding a central oxygen hole in the tip made oxyfuel cutting a practical cutting process. The cutting torch, used by hand or as part of a machine, is used to rapidly cut out steel parts, **Figure 31-41**.

Today a number of manufactured items are touched in some way by the oxyfuel flame. The parts may have been cut out, heated, hardened, or joined with an oxyfuel flame. The expansion of the role of the oxyfuel flame in industry has led to the introduction of new fuel gases and gas mixtures. Each of the new gases has certain advantages and disadvantages. The choice of which gas to use must be based on cost, availability, welder skills and skill changes required, equipment changes, safety, handling, performance, and other concerns. The information supplied for a special gas often points out its strengths and may use comparisons to prove its advantages.

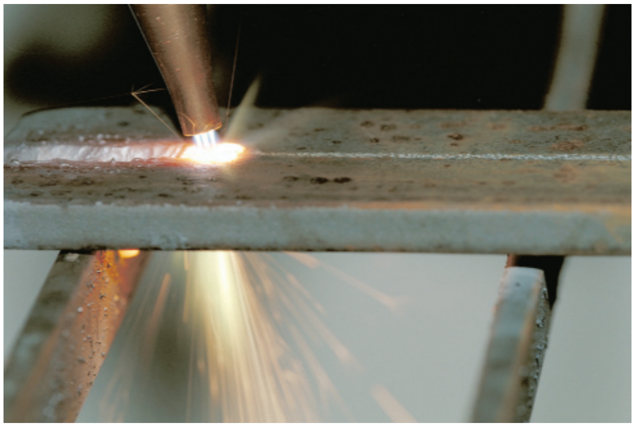

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FIGURE 31-41 Modern hand-held cutting torch.

Characteristics of the Fuel-Gas Flame

The data available for fuel-gas flame characteristics are not gathered in a consistent manner. Temperature and heat, for example, are very basic physical facts about the flame of a specific gas. But even these facts can be misleading. The flame condition, such as neutral, oxidizing, or **carbonizing (carburizing)**, and/or the purity of the gases being used will affect the temperature of the flame. The method by which the temperature is measured also affects its value. The highest potential temperature values are determined by chemical analysis and by the calculation of the theoretical energy released. However, no combustion is perfect, so this temperature is never attained. An infrared analysis or **optical pyrometer** of the flame gives the highest temperature in the flame. But this temperature is concentrated in a thin layer around the inner cone and is so small that it is not of practical use.

The optical pyrometer and the infrared analysis both give an accurate temperature reading, but where the temperature is measured makes a difference.

Differences in heat values may also be misleading, depending on how they are obtained. The temperatures, heat, and other flame characteristics noted in this chapter are as close as possible to those that occur during use. They are not necessarily the highest or lowest possible values and, therefore, should not be considered absolute. However, they can be compared with each other for the purpose of selecting a fuel gas.

FUEL GASES

Most fuel gases used for welding are **hydrocarbons**. The gases are made up of hydrogen (H) and carbon (C) atoms. The atoms are bound together tightly to form **molecules**. Each molecule of a specific gas has the same type, number, and arrangement of **atoms**. The number of atoms in a molecule of gas varies from one gas to another. A molecule of acetylene is made up of two hydrogen (H) atoms and two carbon (C) atoms (C_2H_2). A molecule of propane is made up of eight hydrogen (H) atoms and three carbon (C) atoms (C_3H_8). The chemical formulas for these two fuel gases are shown in **Figure 31-42**.

If a mixture of acetylene (C_2H_2) and oxygen (O_2) is ignited, the acetylene molecule bonds are broken, and new bonds among the hydrogen, carbon, and oxygen atoms are formed. The breaking down of acetylene molecules releases energy in the form of heat and light. The rate at which this reaction occurs results in a change in temperature. The formation of new

C_2H_2
ACETYLENE

$CH_3CH_2CH_3$
PROPANE

FIGURE 31-42 Chemical formulas for two hydrocarbons used as fuel gases.

bonds with the oxygen releases still more energy. This chemical reaction, known as **combustion**, is rapid oxidation.

The number of oxygen atoms required to completely combust the fuel gas varies depending on its molecular makeup. **Table 31-3** lists some fuel gases and the amount of oxygen required to complete the reaction in the flame.

Combustion of acetylene is divided into two separate chemical reactions. The first reaction is referred to as **primary combustion**, and the second reaction is referred to as **secondary combustion**, **Figure 31-43**.

In the primary reaction of acetylene (C_2H_2), the oxygen (O_2) atoms unite with the carbon (C) atoms. This reaction liberates energy and forms carbon monoxide (CO) and free hydrogen, **Figure 31-44**.

In the secondary reaction, oxygen (O_2) from the surrounding air unites with free hydrogen (H) to form water vapor (H_2O) and liberates more heat. Also, the carbon monoxide (CO) unites with additional oxygen (O_2) from the air to form carbon dioxide (CO_2), **Figure 31-45**.

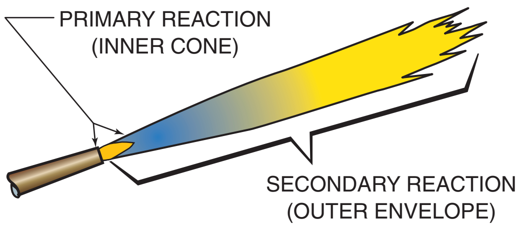

FIGURE 31-43 Parts of an oxyfuel flame.

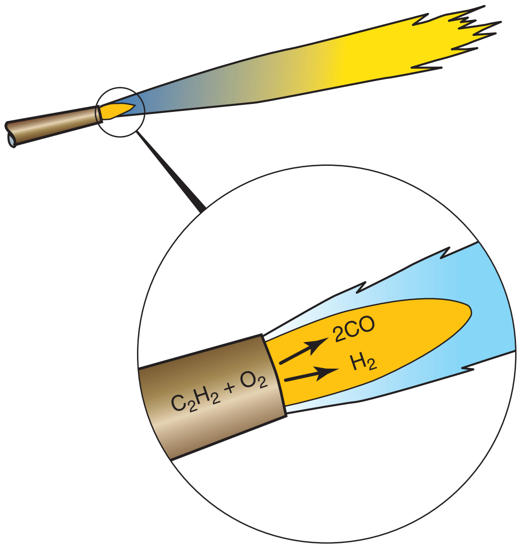

FIGURE 31-44 Primary flame reaction (with acetylene as the fuel gas).

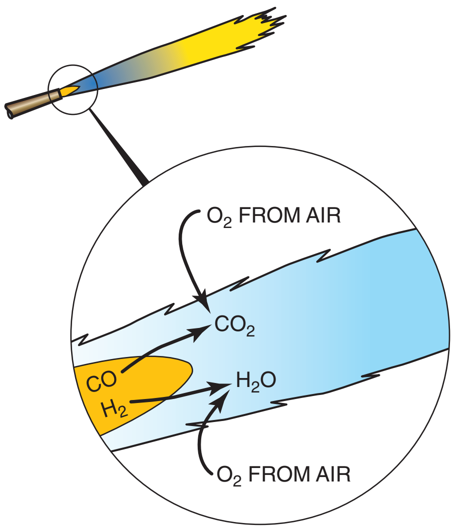

FIGURE 31-45 Secondary flame reaction.

	Cu ft/cu ft			
	Total O_2 Required	Supplied O_2 through Torch*	% Total through Torch	Cu ft O_2 per lb of Fuel
Acetylene—5589°F/1470 Btu	2.5	1.3	50.0	18.9
MAPP® gas—5301°F/2406 Btu	4.0	2.5	62.5	22.1
Natural gas—4600°F/1000 Btu	2.0	1.9	95.0	44.9
Propane—4579°F/2498 Btu	5.0	4.3	85.0	37.2
Propylene—5193°F/2371 Btu	4.5	3.5	77.0	31.0

*Balance of total oxygen demand is entrained in the fuel-gas flame from the atmosphere.

TABLE 31-3 Oxygen Consumption for Fuels (Neutral Flame)

The final products of all clean-burning hydrocarbon flames are the same—water vapor and carbon dioxide. The temperature, rate of combustion, and quantity of heat release are the characteristics that make each flame different. These characteristics make some gases better than others for certain operations.

Flame Rate of Burning

The **combustion rate** or rate of propagation of a flame is the rate or speed at which the flame burns. The combustion or burn rate of a fuel gas is given in feet per second (meters per second).

The combustion rate of a gas is determined by the amount of **heat energy** required to break the bonds between the atoms of its molecules and by the amount of heat energy liberated as the bonds are broken. The ratio of fuel to oxygen and the homogeneity of their mixture also affect the propagation rate.

A homogeneous mixture of 50% acetylene and 50% oxygen has a burn rate of 22.7 ft/sec (6.9 m/sec). As the percentage of oxygen in the mixture increases, the burn rate increases; as the percentage of oxygen decreases, the burn rate also decreases.

The higher the combustion rate of an oxygen fuel mixture, the more prone the mixture is to **backfire** or **flashback**. **Table 31-4** lists the combustion rates for most fuel gases.

EXPERIMENT 31-2

Burn Rate

Using properly set-up and adjusted oxyfuel welding equipment, striker, goggles, gloves, and any other required safety equipment, you are going to observe how changing the mixture ratios of oxygen and acetylene affects the combustion rate.

Set both regulators at 5 psig (35 kPag) and purge the lines as required. With only the acetylene gas torch valve on, use the striker to light the torch. Adjust the gas valve until the flame stops smoking, **Figure 31-46**. Turn on the oxygen torch valve and note the immediate reduction in the flame size. Continue opening the valve until the flame is at a neutral setting, **Figure 31-47**. With the flame at a neutral setting, the total flame size is smaller than it was with just the acetylene even though a larger total volume of gas is coming from the tip. Now increase the oxygen flow by opening the valve more, and notice that the size of the flame again decreases, **Figure 31-48**.

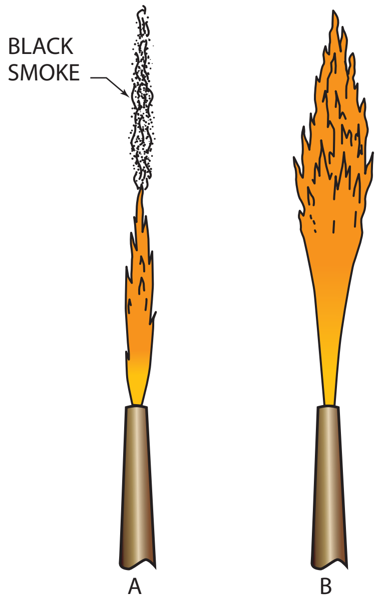

FIGURE 31-46 Adjust the gas valve until the flame stops smoking.

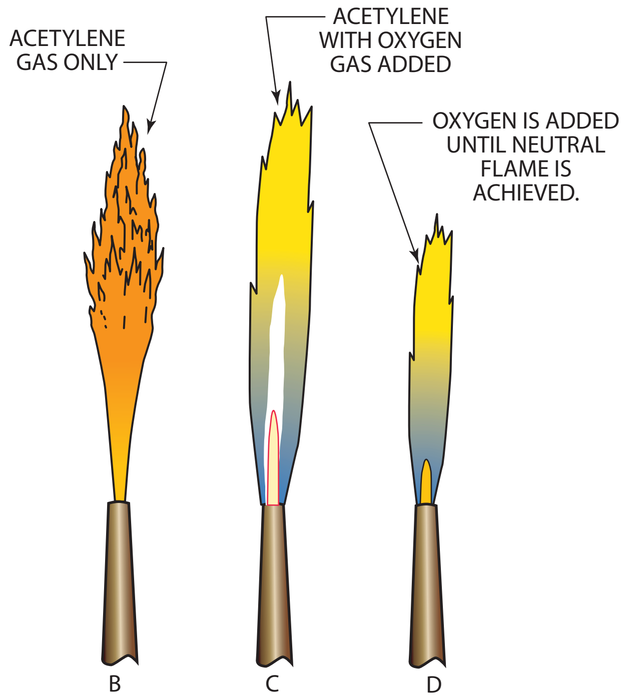

FIGURE 31-47 Achieving the neutral setting of the flame.

Fuel Gas and Oxygen Mixtures Burn Rates						
Burning Velocity	Acetylene	MAPP®	Natural Gas	Propane	Propylene	Hydrogen
ft/sec	22.7	15.4	15.2	12.2	15.1	36
mm/sec	6097	4694	4633	3718	4602	6540

TABLE 31-4 Combustion Rates

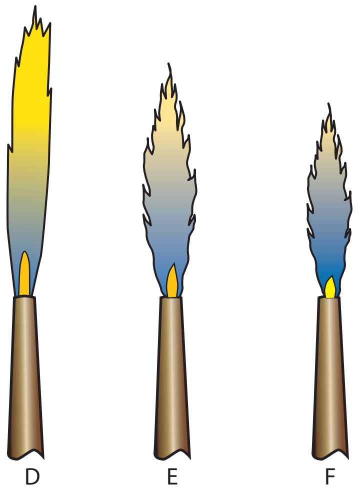

FIGURE 31-48 An increase in oxygen flow again decreases the size of the flame.

In this experiment you have observed that as the percentage of oxygen in the fuel gas increases, the flame propagation or burning rate also increases. This increase is indicated because, even with the increase in total volume of gas, the actual size of the flame decreases.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

CAUTION

An extremely oxygen-rich fuel-gas mixture may have a combustion rate that is greater than the gas flow rates of large tips, resulting in a backfire or flashback. If this occurs, close the oxygen valve immediately.

ACETYLENE (C_2H_2)

Acetylene (C_2H_2) is the most frequently used fuel gas. The mixture of oxygen and acetylene produces a high-heat and high-temperature flame that is widely used for welding, cutting, brazing, heating, metallizing, and hard-surfacing.

Acetylene is produced by mixing calcium carbide (CaC_2) with water (H_2O). Calcium carbide is produced by smelting coke (a coal by-product) and lime in air-tight electric arc furnaces. After smelting, the calcium carbide is cooled, crushed, and packed in dry, air-tight containers. Either a fixed or portable acetylene generator, **Figure 31-49**, is used to mix the calcium carbide with water. In the generator, crushed calcium carbide is dropped into a large tank of water. The carbon (C) in calcium carbide (CaC_2) unites with the hydrogen (H) in water (H_2O) to form two products. These two products are acetylene (C_2H_2), which bubbles out, and calcium hydroxide [$Ca(OH)_2$], which drops to the bottom, **Figure 31-50**. The acetylene gas is drawn off and may be used immediately or pumped into storage cylinders for later use.

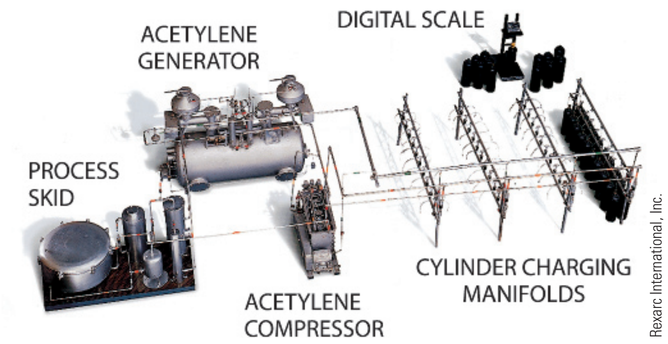

FIGURE 31-49 Acetylene generator.

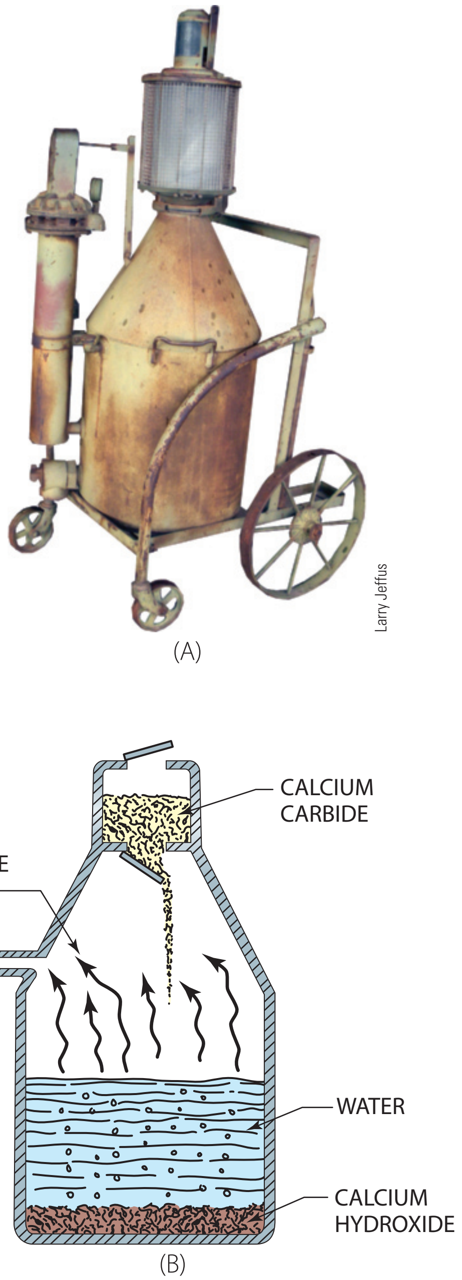

FIGURE 31-50 (A) Acetylene generator used in the early 1900s. (B) An acetylene generator is used to mix calcium carbide with water.

Acetylene is colorless, is lighter than air, and has a strong garlic smell. Acetylene is also unstable at pressures above 30 psig (200 kPag) or at temperatures above 1435°F (780°C). Above the critical pressure or temperature, an explosion may occur if acetylene rapidly decomposes (explodes). This explosion can occur without the presence of oxygen and may occur as a result of electrical shock or extreme physical shock.

CAUTION

Because of the instability of acetylene, it must never be used at pressures above 15 psig (100 kPag) or subjected to any possible electrical shock, excessive heat, or rough handling. Acetylene must not be manifolded or distributed through copper lines because it forms copper acetylide, which is explosive.

Acetone

Acetone, which is a liquid solvent, is used inside acetylene cylinders to absorb the gas and make it more stable. The cylinder is filled with a porous material and then acetone is added to the cylinder, where it absorbs approximately 24-times its own weight in acetylene. Acetone absorbs acetylene in the same manner as water absorbs carbon dioxide in a carbonated drink. As the acetylene is drawn off for use, it bubbles out of the acetone. Excessively high withdrawal rates will cause the acetylene to boil out of the acetone. This rapid boiling can cause a portion of the acetone to be carried out of the cylinder with the acetylene, **Figure 31-51**. Withdrawing the acetone-acetylene mixture and burning it in the flame will contaminate the weld and may damage the rubber seals and internal parts of the regulator and other equipment. In addition to the danger caused by damaged equipment, the cylinder itself may be damaged, resulting in another hazard.

The withdrawal rate of gas from a cylinder should not exceed one-seventh of the total cylinder capacity per hour. **Table 31-5** lists the flow rates in cubic feet per hour (liters per minute) for various torch tip sizes. It also lists the minimum cylinder size to be used with a single torch. If more than one torch is to be used with a cylinder, the draw rates of the tips should be added together to obtain the minimum cylinder size or the number of cylinders that must be manifolded together. As the gas from the cylinder(s) is emptied, a new maximum withdrawal rate must be calculated based on current cylinder capacity.

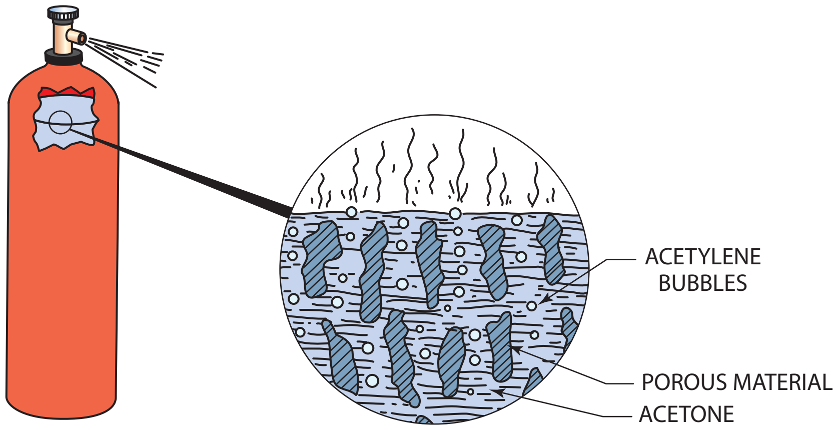

FIGURE 31-51 Acetylene coming out of solution.

Tip Orifice Size—Drill No.	Thickness of Metal—in. (mm)		Oxygen and Acetylene Pressure—psi (kg/cm²)		Acetylene Flow Rate—cfh (L/min)*		Oxygen Flow Rate—cfh (L/min)	
70	1/64	(0.4)	1	(0.0703)	0.1	(0.0471)	0.1	(0.0471)
65	1/32	(0.8)	1	(0.0703)	0.4	(0.188)	0.4	(0.188)
60	1/16	(1.6)	1	(0.0703)	1	(0.4719)	1.1	(0.519)
59	3/32	(2.4)	2	(0.1406)	2	(0.943)	2.2	(1.038)
53	1/8	(3.2)	3	(0.2109)	8	(3.775)	8.8	(4.152)
49	3/16	(4.8)	4	(0.2812)	17	(8.022)	18	(8.494)
43	1/4	(6.4)	5	(0.3515)	25	(11.797)	27	(12.741)
36	5/16	(8.0)	6	(0.4218)	34	(16.044)	37	(17.460)
30	3/8	(9.5)	7	(0.4921)	43	(20.291)	47	(22.179)

*This flow rate must not exceed 1/7 of the cylinder's capacity per hour. For example, a large acetylene cylinder contains approximately 275 cu ft (7788 L) and its withdrawal rate must not exceed 39 cfh (18.40 L/min).

TABLE 31-5 Flow Rates for Various Tip Sizes

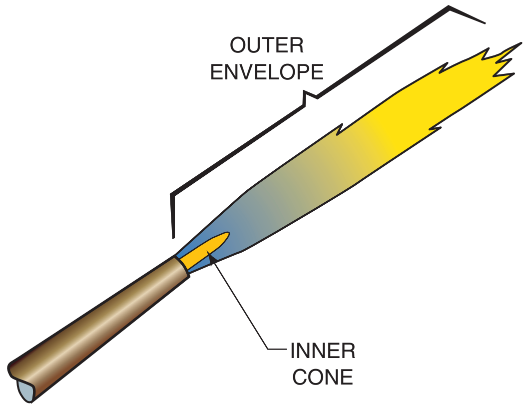

FIGURE 31-52 Parts of a flame.

Heat and Temperature of Acetylene

The neutral oxyacetylene flame burns at a temperature of approximately 5589°F (3087°C). The maximum temperature of a strongly **oxidizing flame** is approximately 5615°F (3102°C). The flame burns in two parts—the **inner cone** and the **outer envelope**; refer to **Figure 31-52**. The heat produced by the flame can be divided into portions produced in the inner cone and outer envelope. The inner cone produces 507 Btu per cubic foot of gas (19 kilogram-calories per cubic meter), and the outer envelope produces 963 Btu per cubic foot of gas (36 kg-cal/m^3). The total heat produced by the flame is 1470 Btu/ft^3 (55 kg-cal/m^3).

The high temperature produced by the oxyacetylene flame is concentrated around the inner cone, **Figure 31-53**. As the flame is moved back away from the work, the localized heating is reduced quickly. For welding, this highly concentrated temperature is the greatest advantage of the oxyacetylene flame over other oxyfuel gases. The molten weld pool is easily controlled by the torch angle and position of the inner cone to the work.

Although more heat is produced in the secondary flame than in the primary flame, the temperature is much lower. The lower temperature and the relatively low concentration of the heat produced by the outer flame are distinct disadvantages of the oxyacetylene flame when it is used for heating. The flame must be held close to the work and moved constantly to obtain uniform heating of large parts.

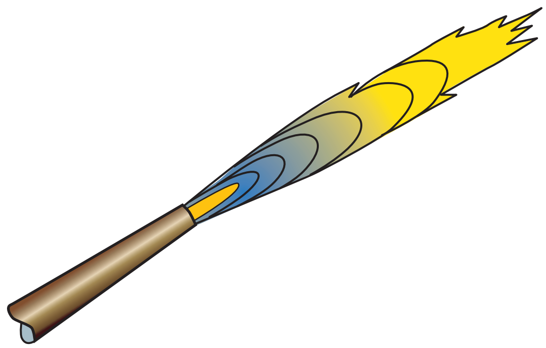

FIGURE 31-53 Thermal gradients of a flame.

Liquefied Fuel Gases

Some fuel gases are available in liquefied form in pressurized cylinders. **Liquefied fuel gases** can be obtained in either individual cylinders or bulk tanks. The high-volume use of fuel gas often requires excessive cylinder inventory and handling. Setting up a bulk system will eliminate much of the cylinder inventory and handling.

Pressure

The pressure in a cylinder containing a liquefied gas is not an indication of the level of gas in the tank. The pressure is based on the type of gas and the gas temperature. The gas pressure of a liquid increases as the temperature increases, and it decreases as the temperature decreases. At high temperatures, approximately 200°F (93°C), the pressure may cause the release valve to open to release excessive pressures over 375 psig (2690 kPag). At extremely low temperatures, the cylinder may not have any working pressure. For example, at temperatures below 31°F (−1°C), butane has no pressure. **Table 31-6** lists the gas pressures for various gases at different temperatures.

High withdrawal rates of gas from liquefied gas cylinders will cause a drop in pressure, a lowering of the cylinder temperature, and the possibility of freezing the regulator. As a gas is drawn out of the cylinder, the liquid inside absorbs heat from the outside to produce more gas vapor, **Figure 31-54**. If the gas is drawn out faster than heat can be absorbed, then the cylinder will begin to cool off. A ring of frost may appear around the bottom of the cylinder. If high withdrawal rates continue, then the regulator may also start to ice up. For applications requiring high withdrawal rates, the cylinder should be placed in a warm area.

CAUTION

Heat should never be applied directly to a cylinder.

Methylacetylene-Propadiene (MPS)

Many different **methylacetylene-propadiene (MPS)** gases are in use today as fuel gases for oxyfuel cutting, heating, brazing, metallizing, and, to a limited extent, welding. MPS gases are mixtures of two or more of the following gases: propane (C_3H_8), butane (C_4H_{10}), butadiene (C_4H_6), methyl acetylene (C_3H_4), and propadiene (C_3H_4). The mixtures vary in composition and characteristics from one manufacturer to another. However, all manufacturers provide MPS gases as liquefied gases in pressurized cylinders.

Production There are a number of MPS gases marketed: **MAPP**®, Chem-O-Lean®, Apachi Gas®, FG-2 Gas®, Flamex®, and natural gas, among others. The gases may be

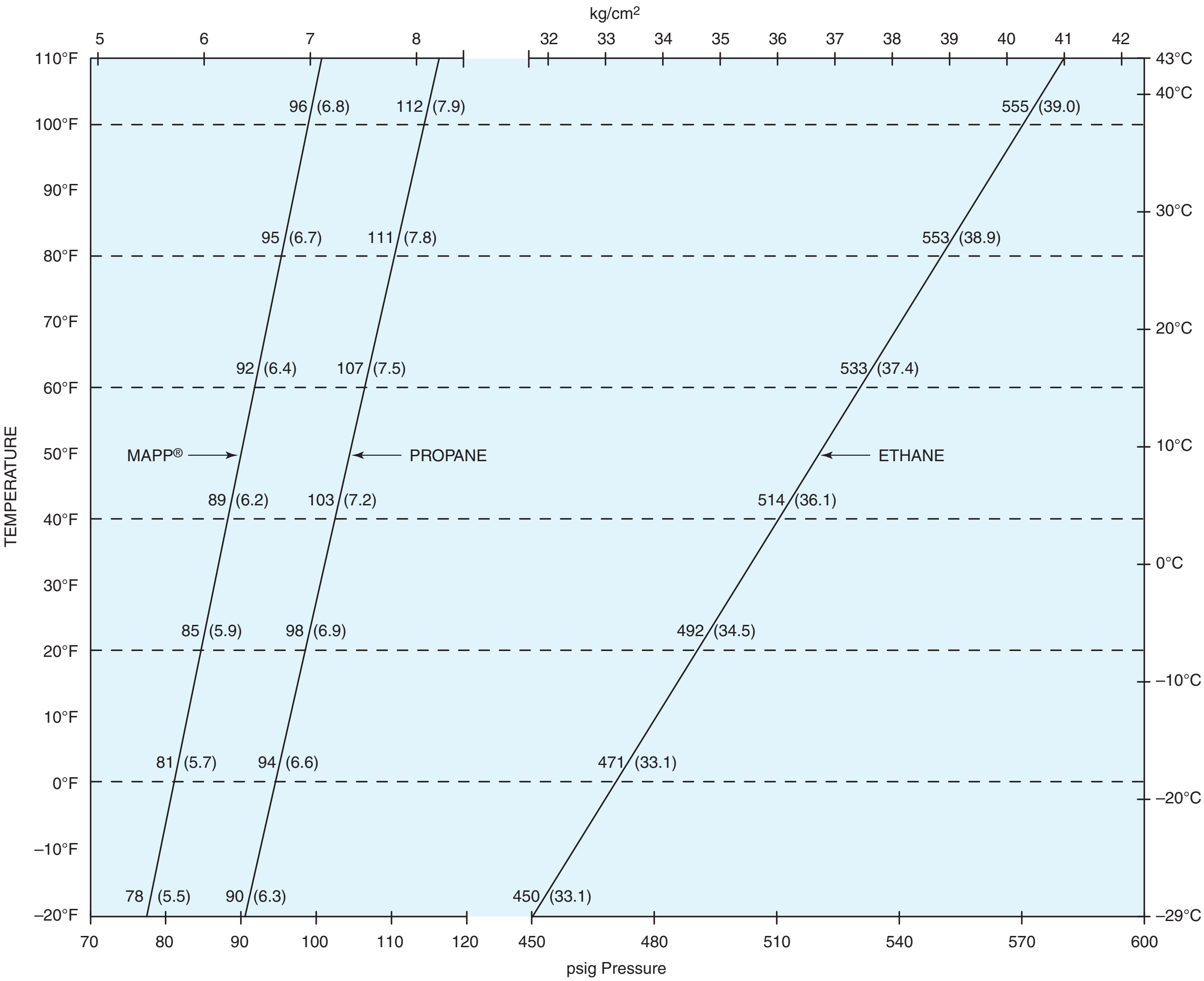

TABLE 31-6 Gas Pressures Vary with Temperature Changes

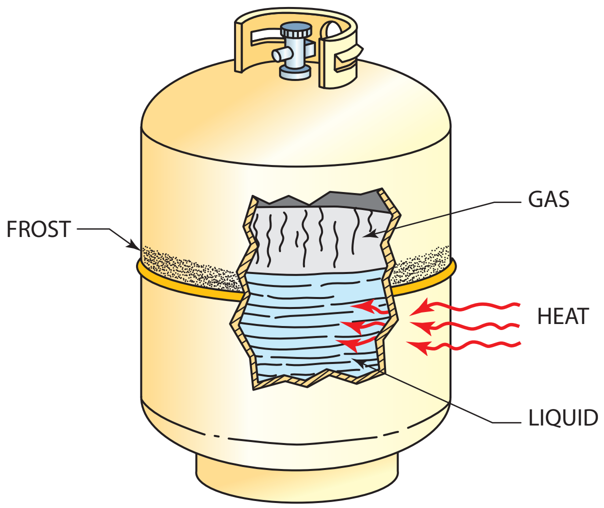

FIGURE 31-54 The heat absorbed by the liquid propane causes it to change to a gas.

mixed by a local supplier as the cylinders are filled, or the supplier may receive the gas premixed. In cylinders that are stored for a long time, some mixtures tend to separate. Before using the cylinder, it should be moved enough to remix the gases inside. In some cylinders a **piccolo tube** is used, **Figure 31-55**, to improve the mixing of the gas by causing the liquid to be agitated as it is used. Without a means of stirring the gas, some MPS gases may burn differently when the cylinder is full than when it is nearly empty.

Temperature and Heat of MPS Gases MPS gases have a neutral oxyfuel flame temperature of approximately 5301°F (2927°C). The exact temperature varies with the specific mixture. The flame temperature and heat are high enough to be used for welding, but MPS gases are seldom used for this purpose.

The heat produced by the primary flame, approximately 570 Btu/ft^3 (21 kg-cal/m^3), is approximately the same as that produced by acetylene. The secondary flame

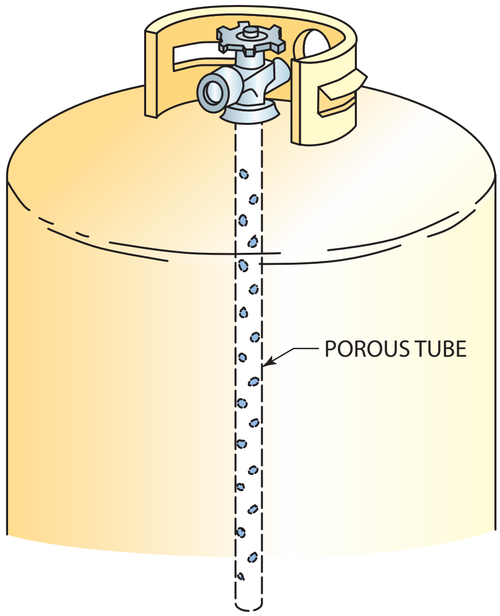

FIGURE 31-55 A piccolo tube helps keep gases mixed during use.

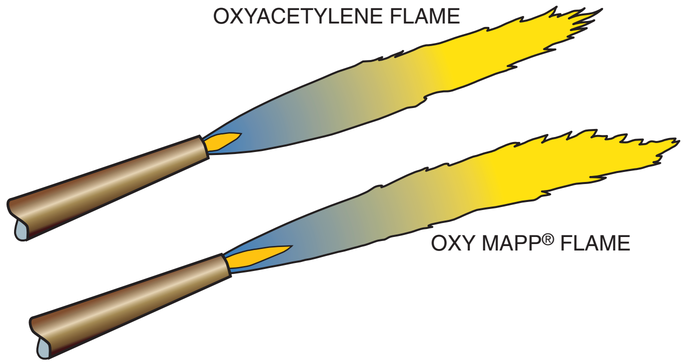

FIGURE 31-56 The inner cone and outer envelope of a MAPP® flame are longer than an equal-volume flame of acetylene because of the slower burn rate of MAPP®.

METHYLACETYLENE PROPADIENE

FIGURE 31-57 MAPP® gas molecules.

produces approximately 1889 Btu/ft^3 (70 kg-cal/m^3) of heat or twice the heat of acetylene. These values make MPS gases much better than acetylene for heating, brazing, and some types of cutting. The slower burn rate of these gases results in a poorly concentrated flame, which is difficult to use for welding.

MAPP®

MAPP® gas is the trade name for the stabilized liquefied mixture of methylacetylene (CH_3:C:CH) and propadiene (CH_2:C:CH_2) gases. Oxy MAPP® combusts with a high-heat, high-temperature flame that works well for cutting, heating, brazing, and metallizing, **Figure 31-56**.

The gases mixed to produce MAPP® have the same atomic composition. This means that three carbon and four hydrogen atoms are present in each molecule of gas. Molecules of each gas have the same mass and size even though they are shaped differently, **Figure 31-57**. Because they are the same mass and size, the gas molecules form a stable mixture that remains uniformly mixed in the cylinder. The stabilization of mixture ensures a uniform and consistent flame for easier quality control.

Oxy MAPP® Flames

Oxy MAPP® produces a **neutral flame** temperature of 5301°F (2927°C) that yields a heat value of 517 Btu/ft^3 (19 kg-cal/m^3) in the primary flame and 1889 Btu/ft^3 (70 kg-cal/m^3) in the secondary flame. The total heat value is 2406 Btu/ft^3 (90 kg-cal/m^3). **Table 31-7** compares the temperatures and heat produced by five different fuel

Fuel	Neutral Flame–Temperature °F (°C)	Primary Flame Btu/ft³ (kg-cal/m³)	Secondary Flame Btu/ft³ (kg-cal/m³)	Total Heat Btu/ft³ (kg-cal/m³)
Acetylene	5589 (3087)	507 (4510)	963 (8570)	1470 (13,090)
MAPP® gas	5301 (2927)	517 (4600)	1889 (16,820)	2406 (21,420)
Natural gas	4600 (2538)	11 (98)	989 (8810)	1000 (8900)
Propane	4579 (2526)	255 (2270)	2243 (19,970)	2498 (22,240)
Propylene	5193 (2867)	438 (3900)	1962 (17,470)	2371 (21,110)

TABLE 31-7 Heating Values of Major Industrial Fuel Gases (Combusted with Pure Oxygen)

gases. The difference between the temperature produced by a neutral oxyacetylene flame and a neutral oxy MAPP® flame is only 288°F (142°C). Both flames are well above the approximate 2800°F (1536°C) temperature required to melt mild steel. Although MAPP® is not normally recommended for use in gas welding, it can be used successfully. Because the secondary flame of MAPP® produces almost twice the heat of the acetylene flame, distortion is more of a problem with MAPP® than with acetylene. Also, it is more difficult to melt the root of a joint using MAPP®.

Because of the higher heat, the sides of the joint melt first, **Figure 31-58**. This is not as much of a problem with other joint designs.

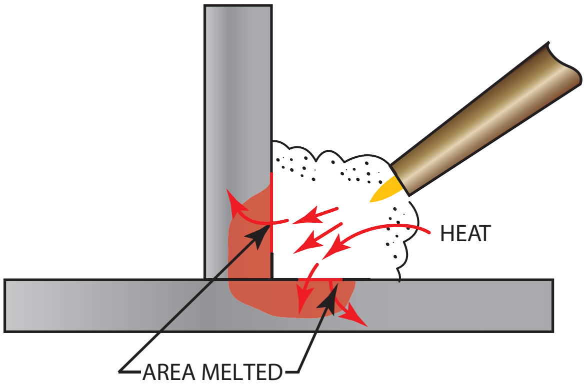

FIGURE 31-58 Secondary heat of an oxy-MAPP® flame causes the sides of a tee joint to melt before the root of the joint melts.

All gases used as alternatives to acetylene are safer to use, store, and handle. MAPP® has each one of the safety features of the other fuel gases. These safety features include shock stability, narrow explosive limits in air, no pressure limitation, and slow burning velocities, **Figure 31-59**. Another safety advantage of MAPP® is its smell. The odor of MAPP® can be detected when there are as few as 100 parts per million (ppm) of the gas or 1/340 of its lower explosive limit in air. By law, propane, natural gas, and propylene must have an odor added to them so that they can be detected at a concentration of 1/15 of their lower explosive limit in air. The ability to detect even small leaks can save gas and avoid the possibility of explosions. The foul odor of MAPP® allows leaks to be found more than 22-times faster than acetylene leaks can be found.

Table 31-8 compares acetylene, MAPP® gas, and propylene for various procedures. The higher the number given, the better the performance of the gas for that procedure.

PROPANE AND NATURAL GAS

Propane and natural gas find limited use in the welding industry. Because of their relatively low-temperature, low-heat flames, they are seldom used for purposes other than heating and as preheat fuels for cutting.

The major advantage of propane and natural gas is that they are often used for heating the shop. Therefore, a supply of these gases is readily available. The handling of cylinders is reduced or eliminated because natural gas is

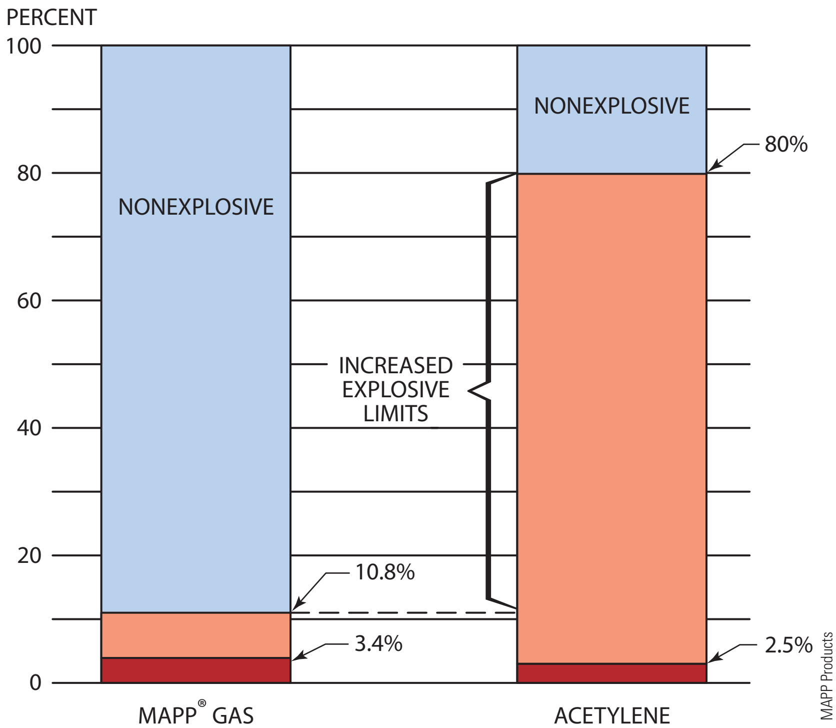

FIGURE 31-59 Explosive limits of MAPP® gas in air.

Application	Acetylene	MAPP Gas	Propylene
Cutting			
Under 3/8 in. thick	100	95	90
5/8 in. to 5 in. thick	95	100	95
Over 5 in. thick	80	100	95
Cutting dirty or scaled surfaces	100	95	80
Repetitive cutting	100	100	80
Stack cutting	90	100	95
Cutting low–alloy specialty steels	100	90	80
Beveling	100	100	85
Cutting rounds	95	100	85
Piercing	100	100	85
Blind-hole piercing	100	90	80
Rivet washing	100	95	80
Gouging	100	100	85
Wire metallizing	80	100	90
Powder metallizing	100	0	0
Heating, stress relief, bending	70	100	90
Deep flame hardening	90	100	90
Shallow flame hardening	95	100	80
Cobalt-base hardsurfacing	100	0	0
Other alloy hardsurfacing	100	85	70
Welding	100	70	0
Braze welding	100	90	70
Brazing	100	100	90

TABLE 31-8 Average Performance Ratings of Some Oxyfuel Flames

piped directly to the shop and propane can be delivered in bulk tanks. Both gases are easily piped through the shop.

Propane and natural gas are both obtained from the petroleum industry. Natural gas comes from gas wells, and propane is produced from oil and gas at refineries. An artificial odor, a mercaptan chemical, must be added so that leaks can be detected for safety purposes.

Chemically, propane is C_3H_8; natural gas is mostly methane (CH_4) and ethane (C_2H_6). The major disadvantage is that both gases consume a large amount of oxygen. Propane requires 85% of the flame's oxygen from the cylinder, and natural gas requires 95% of its oxygen from the cylinder, compared with an oxygen consumption of as little as 50% for the oxyacetylene flame.

HYDROGEN

Oxyhydrogen produces only a primary combustion flame, unlike hydrocarbon gases, which have both primary and secondary combustion. The hydrogen flame is almost colorless and can be seen only when dirt, dust, and other contaminants from the air glow while burning in the flame. Hydrogen is not widely used in welding because of its expense, its limited availability, and some myths about its safety.

Hydrogen has the fastest burning velocity of any of the fuel gases at 36 ft/sec (10.9 m/sec). Acetylene has a burn rate of less than one-half that of hydrogen. Hydrogen has a very slight tendency to backfire, yet it does not flash back. Unlike acetylene, which can explosively decompose without oxygen, hydrogen cannot be made to react without the presence of sufficient oxygen.

Hydrogen is much lighter than air. Therefore, when it is released, it diffuses quickly, reducing the possibility of accidental combustion. If a large quantity of hydrogen is allowed to burn uncontrolled, the gas rises into the flame. This means it burns in an upward direction, away from people in an area. Most other gases burn in a downward direction, which can trap people in an area. The chance of large quantities of hydrogen exploding is limited. For example, when the hydrogen-filled airship, the Hindenburg, caught fire and burned in 1931, no explosion occurred, and most of the people on board the airship survived.

The low flame temperature restricts the use of the **oxyhydrogen flame** to cutting, usually underwater, and to gas welding and brazing on low-temperature metals such as aluminum. The flame can be made reducing (needing oxygen) to help protect the aluminum from oxidation, without having excessive carbon to contaminate the weld. The finished flame product is water (H_2O). Only one-quarter of the flame oxygen comes from the cylinder. The rest comes from the air surrounding the flame.

Two major safety problems exist when hydrogen is used as a fuel gas. First, hydrogen has no smell, which makes it difficult to detect leaks. Second, the molecule is extremely small so that it leaks easily. When hydrogen is used, an active leak-checking schedule must be followed to find small problems before they develop into disasters. It is possible for a leak to be on fire and not be noticed because the hydrogen flame is almost invisible.

THINK GREEN

Nonpolluting Fuel-Gas Flame

The oxygen and hydrogen flame is the only 100% nonpolluting fuel-gas flame. The only by-product from this flame is water vapor. In addition, both oxygen and hydrogen gases can be produced with electrolysis of water by using renewable energy such as solar or wind.

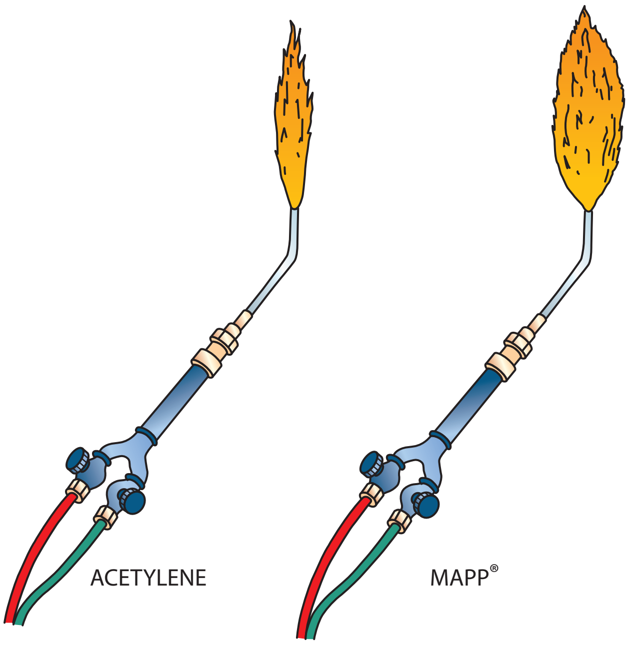

FIGURE 31-61 The second fuel gas flame may be slightly off the tip.

EXPERIMENT 31-3

Oxyfuel Flames

Using an identical torch set with each available fuel gas, you are going to observe the flame as each fuel gas is safely lit, adjusted, and extinguished.

Set all fuel and oxygen regulators at approximately 5 psig (35 kPag). Each torch should have the same size tip. The tip should have an orifice equal to a number 53 to 60 drill. Place the torches on a table with the tips pointed up, **Figure 31-60**.

Starting with the oxyacetylene torch, turn on the fuel-gas valve slightly. Using a flint lighter, light the torch and adjust the gas valve so that the flame is not smoking. After securely placing the lit torch back on the table, repeat the process with all of the other torches. Adjust the flame of each torch to the same size as the acetylene flame, **Figure 31-61**.

Pick up the acetylene torch and move it back and forth, **Figure 31-62A**. The flame should be stable, with only the top deflecting as the torch is moved. Replace the torch carefully on the table.

One at a time, pick up each of the other torches and move them just as you did with the acetylene torch. The flames on these torches will deflect more, and some flames may go out, **Figure 31-62B**. The reason for the difference is that less gas is flowing with each of the other gases. The acetylene flame is more stable because it has the highest flow rate and the highest burn rate. Thus, the flame is more compact.

Turn on the oxygen valve slowly until the acetylene flame is adjusted to a neutral setting. Repeat this procedure with each of the other flames. The flames may blow out as the oxygen is turned on. If this happens, direct the flame

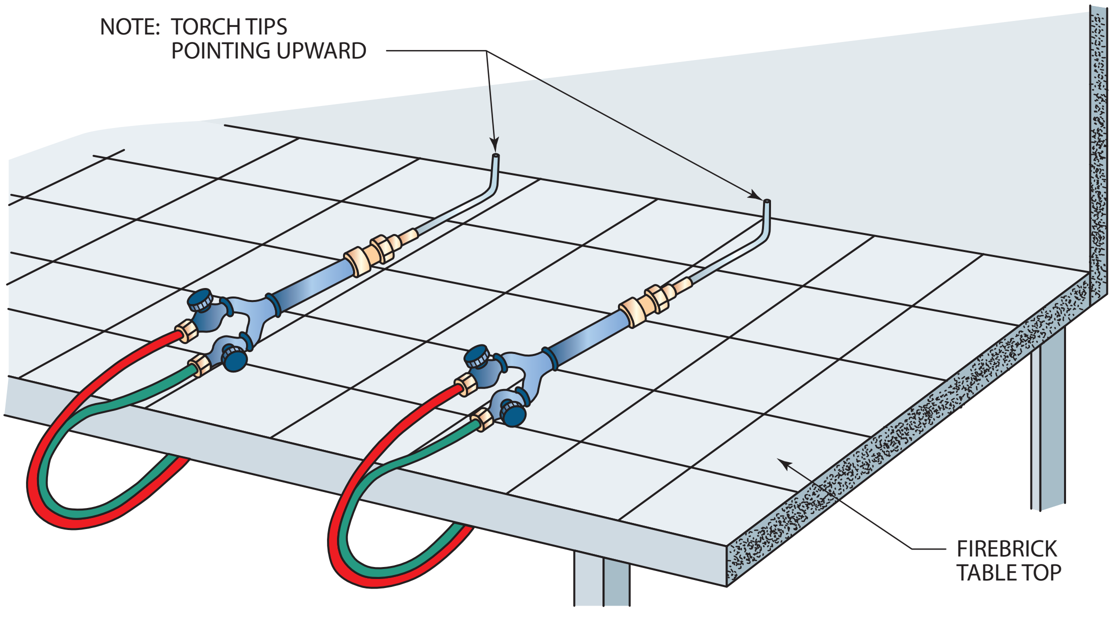

FIGURE 31-60 Torches set up to compare fuel gases.

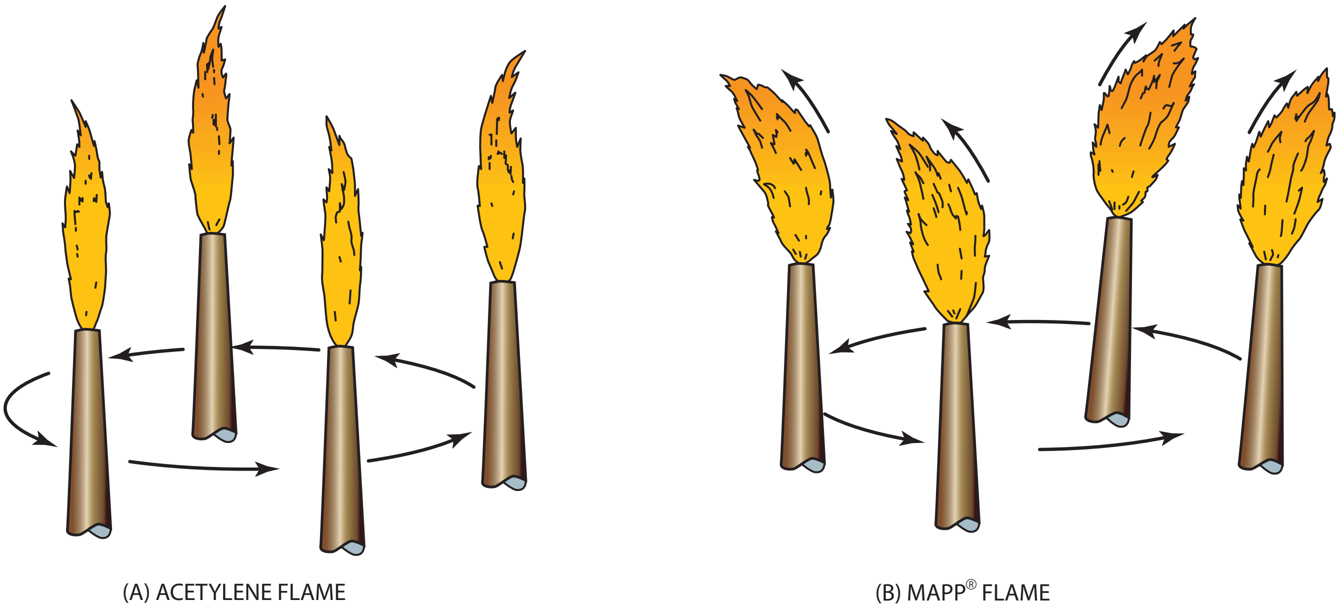

FIGURE 31-62 Move the torches back and forth and watch the flame.

against the firebrick top of the welding table and readjust the oxygen until a neutral flame is reached with each torch. The flames may blow out because of the slow burning velocities of the gases. All the flames should look nearly the same in color, but the inner cone on the acetylene flame will be the shortest, **Figure 31-63**.

Line up the torches and hold the end of a gas welding rod with a 1/8-in. (3-mm) diameter in each flame. The welding rods should all be put in the flames at the same time. They should all be held at the same height above the inner cone, approximately 1/4 in. (6 mm), **Figure 31-64**. Watch as the welding rods melt, each one at a different rate. Cool the welding rods and repeat the experiment with the ends of the welding rods 1/4 in. (6 mm) higher than before. After the welding rods melt, cool and raise the welding rods another 1/4 in. (6 mm). Keep repeating this step until the welding rods stop melting or turning red.

The acetylene flame should melt the low welding rod fastest, but one of the other gases should heat the rod faster as the distance above the inner cone increases.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

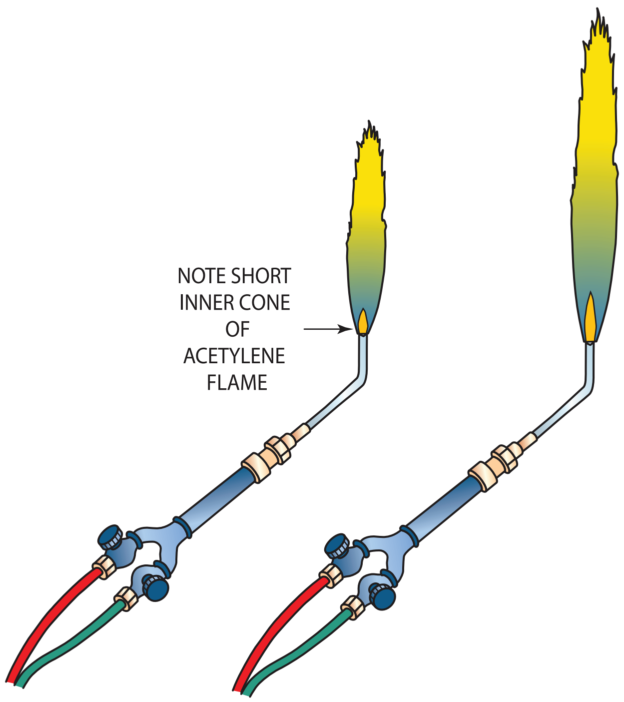

FIGURE 31-63 Compare the flames.

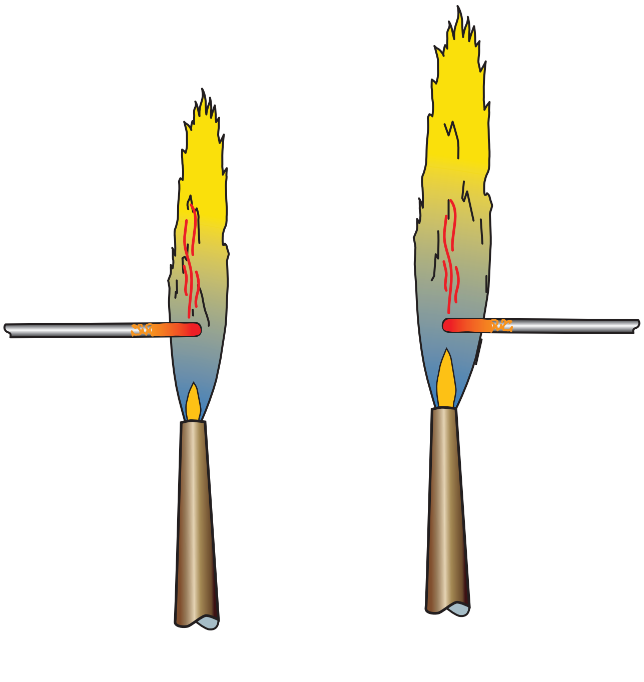

FIGURE 31-64 Observe the degree and rate of heating produced by each flame.

FILLER METALS

Filler metals specifically designed to be used with an oxyfuel torch are generally divided into three groups. One group of welding rods used for welding is designated with the prefix letter *R*. Another group of rods used for brazing is designated with the prefix letter *B*. A third group is used for buildup, wear resistance surfacing, or both. Welding rods in this group may also be classified in one of the other groups, may be patented and use a trade name, or may be tubular with a granular material in the center. The tubular welding rods are designated with an RWC prefix. Some filler metals, for example, BRCuZn, are classified both as a braze welding rod (R) and a brazing rod (B) because they can be used either way.

THINK GREEN

Conserve Filler Metal

The short ends of both welding and brazing rods can be fused together so that the amount of scrap filler metal can be minimized, unlike most other filler metal such as SMAW, GMAW, and FCAW. Being able to use all of the filler metal can create significant savings of shop funds and can reduce waste materials.

Ferrous Metals

Ferrous filler metals are welding rods that are mainly iron. They may have other elements added to change their strength, corrosion resistance, weldability, or another physical property. There are three major American Welding Society (AWS) specifications for ferrous filler metals. These three specifications are A5.2 low-carbon, low-alloy steel; A5.15 cast iron; and A5.9 stainless steel. Within each specification there are classes; for example, in group A5.2 the classes are RG45, RG60, and RG65.

The specifications and classes have minimum and maximum limits for the alloys that are added to provide the required physical properties of the weld they produce. Each manufacturer is free to make changes in the wire composition within the specified limits. The changes generally involve weldability, tensile strength, ductility, cracking, appearance, porosity, impact strength, and hardness.

Physical changes are most often affected by changes in the percentages of alloys of carbon (C), silicon (Si), manganese (Mn), chromium (Cr), vanadium (V), nickel (Ni), and molybdenum (Mo). Contaminants from fuels used in the production of iron, such as phosphorus (P) and sulfur (S), have a negative effect on many of the desired properties, and the amount of contaminants should be kept as low as possible.

Small shops sometimes use other types of wire for weld filler metals. The most popular substitution is often coat-hanger wire. Using such substitutes can cause weld failure. Coat-hanger wires were not manufactured for welding purposes, and their chemistry varies greatly. Porosity inside the weld deposit is common due to levels of phosphorus (P) and sulfur (S) that are higher than acceptable. The painted finish of the wire will burn, causing further weld contamination and fumes that can be hazardous to the welder. Another type of substitute wire is often cadmium (Cd), plated to prevent rust. However, when cadmium is burned or vaporized, poisonous fumes are produced. The only safe filler metals to use are the ones specifically designed for welding.

Mild Steel

Ferrous metal filler rods are generally classified by the AWS as mild steel, low-alloy steel, or cast iron. Mild steel and low-alloy steel are the materials that are most frequently gas welded. They are easily welded without a flux. Cast iron and stainless steels require fluxes and special techniques.

Mild steel and low-alloy gas welding rods are classified by the AWS as RG45, RG60, and RG65. The *R* refers to the welding rod, and the *G* refers to the ability to use gas for welding. The two digits indicate the minimum tensile strength range of the weld metal deposited.

Class RG45 Class RG45 is a general-purpose gas welding rod that is often used for training welders. It has a smooth, shiny molten weld pool that leaves a nice looking bead. The low carbon content helps make low-strength 45,000 psi to 55,000 psi (3163 kg/cm^2 to 3866 kg/cm^2) welds in the tensile strength range that are ductile. Automotive, auto body, wrought iron, and general welding shops use this welding rod for most or all of their gas welding.

Class RG60 Class RG60 welding rods, compared to RG45 welding rods, have a slightly higher carbon content and produce a higher weld strength in the range of

50,000 psi to 65,000 psi (3515 kg/cm^2 to 4569 kg/cm^2). The addition of silicon, manganese, and other metallic elements may improve the retention of carbon or other easily oxidized material. The molten weld pool is not as clear or shiny as that obtained with RG45 welding rods, and the weld bead also may not look as nice. The RG60 welding rod can be used on low-alloy steels requiring good strength and ductility. It is frequently used for mild steel pipe welds, structural shapes, chrome-moly aircraft tubing, American Society of Mechanical Engineers (ASME) code welds, and gas tungsten arc welding.

Class RG65 Class RG65 welding rods are low-alloy, high-strength, 65,000 psi to 75,000 psi (4569 kg/cm^2 to 5272 kg/cm^2), low-creep, corrosion-resistant welding rods. The high content of silicon and manganese helps to retain carbon but may cause a thick, crusty layer of manganese silicate flux ($MnSiO_3$) to float on top of the molten weld pool. Although this molten weld pool has the roughest look, it is the purest and strongest. The RG65 welding rod is used in ASME high-pressure piping, tubing, and gas tungsten arc welding.

CAST IRON

Cast iron filler rods for gas welding are small, round, or square iron castings. The prefix *R*, which refers to the welding rod, is used in front of *CI*, which stands for cast iron. A high-temperature, borax-based flux must be used to prevent the carbon from burning out.

Class RCI Class RCI is the lower-strength filler metal; it has a tensile strength of 20,000 psi to 26,000 psi (1406 kg/cm^2 to 1757 kg/cm^2). This class is recommended for most general cast iron repair and for the buildup and fill-in of damaged castings. The weld can be remachined if necessary.

Compared to RCI welding rods, class RCI-A welding rods have higher tensile strength, in the range of 35,000 psi to 40,000 psi (2460 kg/cm^2 to 2612 kg/cm^2). An RCI-A welding rod is used on alloy cast irons or where higher strengths are required.

PRACTICE 31-1

Setting Up an Oxyfuel Torch Set

This practice requires a disassembled oxyfuel torch set consisting of two regulators, two reverse flow valves, one set of hoses, a torch body, a welding tip, two cylinders, a portable cart or supporting wall, and a wrench. You will assemble the equipment in a safe manner.

1. Safety chain the cylinders separately to the cart or to a wall, **Figure 31-65**. Then, remove the valve protection caps, **Figure 31-66**.
2. Crack the cylinder valve on each cylinder for a second to blow away dirt that may be in the valve, **Figure 31-67**.

Larry Jeffus

FIGURE 31-65 Safety chain cylinder.

Larry Jeffus

FIGURE 31-66 Unscrew the valve protector caps. Put the caps in a safe place because they must be replaced on empty cylinders before they are returned.

Larry Jeffus

FIGURE 31-67 Cracking the oxygen and fuel cylinder valves to blow out any dirt lodged in the valves.

CAUTION

If a fuel-gas cylinder does not have a valve hand wheel permanently attached, then you must use a nonadjustable wrench to open the cylinder valve. The wrench must stay with the cylinder as long as the cylinder is on, **Figure 31-68.**

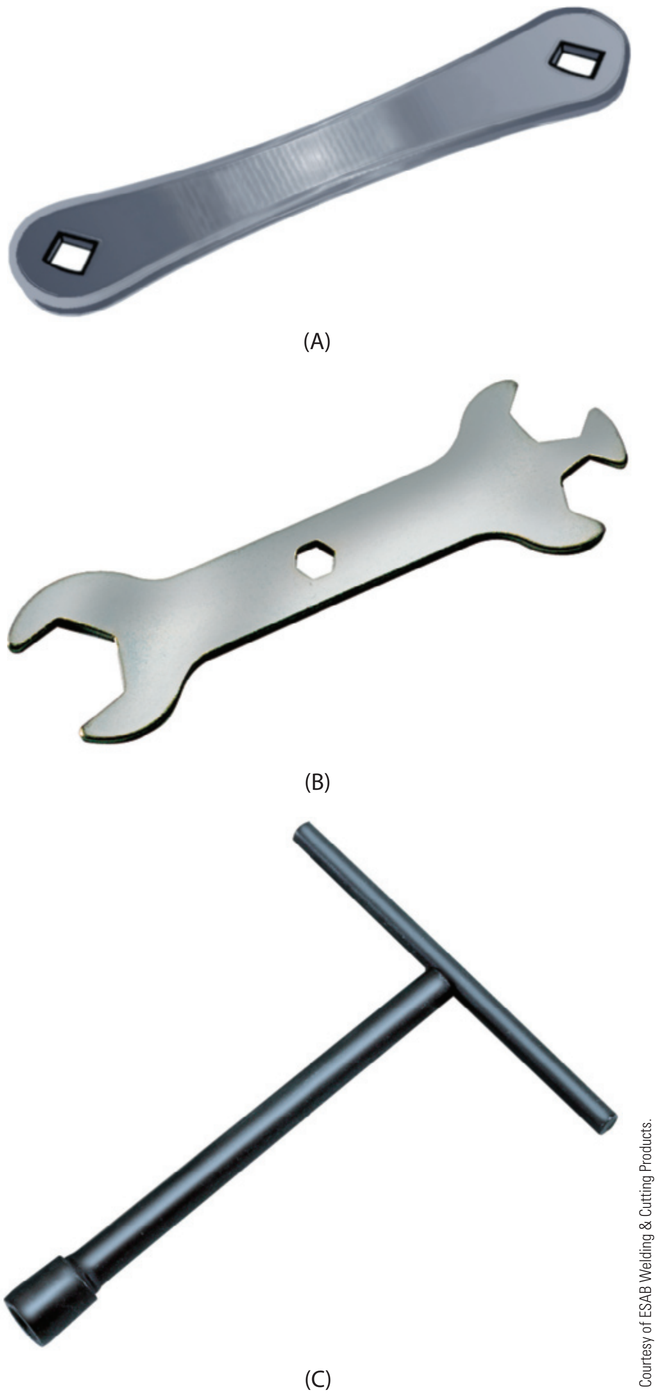

FIGURE 31-68 Nonadjustable wrenches for acetylene cylinders. (A) Small combination wrench. (b) Large combination wrench. (C) T wrench.

1. Attach the regulators to the cylinder valves, **Figure 31-69A**. The nuts can be started by hand and then tightened with a wrench, **Figure 31-69B**.
2. Attach a reverse flow valve or flashback arrestor, if the torch does not have them built into the hose connection, on the regulator or to the hose connection on the torch body, depending on the type of reverse flow valve in the set, **Figure 31-70**. Occasionally test each reverse flow valve by blowing through it to make sure it works properly.
3. Connect the hoses. The red hose has a left-hand grooved nut and attaches to the fuel-gas regulator. The green hose has a right-hand nut without grooves and attaches to the oxygen regulator.
4. Attach the torch to the hoses, **Figure 31-71**. Connect both hose nuts and tighten by hand before using a wrench to tighten either one.

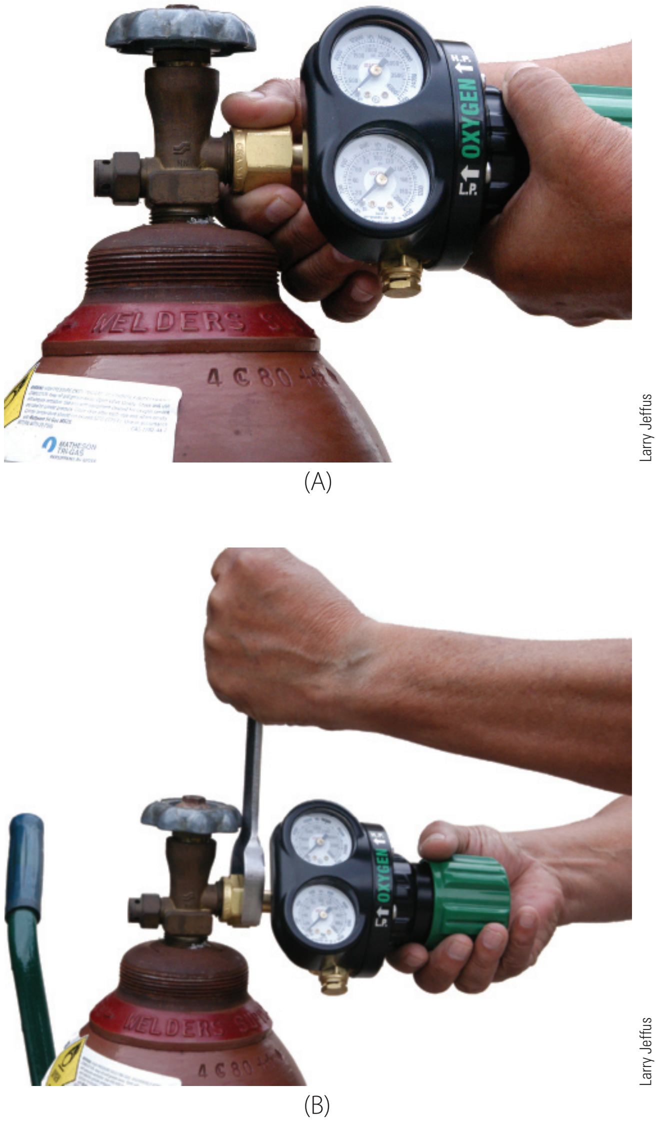

FIGURE 31-69 Attach the oxygen regulator (A) to the oxygen cylinder valve. Using a wrench (B), tighten the nut.

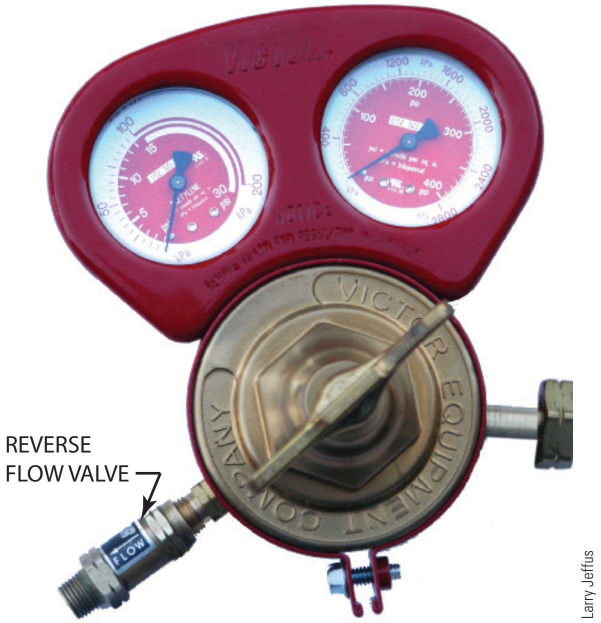

FIGURE 31-70 Install a reverse flow valve if one is not built into the torch body before attaching the hose to the regulator.

FIGURE 31-71 Connect the free ends of the oxygen (green) and the acetylene (red) hoses to the welding torch.

5. Check the tip seals for nicks or the O-rings, if used, for damage. In most cases, tips that have O-ring–type seals are tightened by hand, and tips that have metal-to-metal seals are tightened by using a wrench, but it is best to check the owner's manual or a supplier to determine if the torch tip should be tightened, **Figure 31-72**.

CAUTION

Always stand to one side. Point the valve away from anyone in the area and be sure there are no sources of ignition when cracking the valve.

CAUTION

Tightening a tip the incorrect way may be dangerous and might damage the equipment.

FIGURE 31-72 Select the proper tip or nozzle and install it on the torch body.

Check all connections to be sure they are tight. The oxyfuel equipment is now assembled and ready for use.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 31-2

Turning On and Testing a Torch

Using the oxyfuel equipment that was properly assembled in Practice 31-1, a nonadjustable tank wrench, and a leak-detecting solution, you will pressurize the system and test for leaks.

1. Back out the regulator pressure by adjusting screws until they are loose, **Figure 31-73**.
2. Standing to one side of the regulator, open the cylinder valve slowly so that the pressure rises on the gauge slowly, **Figure 31-74**.
3. Open the oxygen valve all the way until it is sealed at the top, **Figure 31-75**.
4. Open the acetylene or other fuel-gas valve one-quarter turn, or just enough to get gas pressure, **Figure 31-76**. If the cylinder valve does not have a hand wheel, use a nonadjustable wrench and leave it in place on the valve stem while the gas is on.
5. Open one torch valve and point the tip away from any source of ignition, including the cylinders, regulators, and hoses. Slowly turn in the pressure-adjusting screw until gas can be heard escaping from the torch. The gas should flow long enough to allow the hose to be completely **purged** (emptied) of air and replaced by the gas before the torch valve is closed. Repeat this process with the other gas.
6. After purging is completed, and with both torch valves off, adjust both regulators to read 5 psig (35 kPag), **Figure 31-77**.
7. Spray a leak-detecting solution on each hose and regulator connection and on each valve stem on the torch and cylinders. Watch for bubbles, which indicate a leak. Turn off the cylinder valve before tightening any leaking connections, **Figure 31-78**.

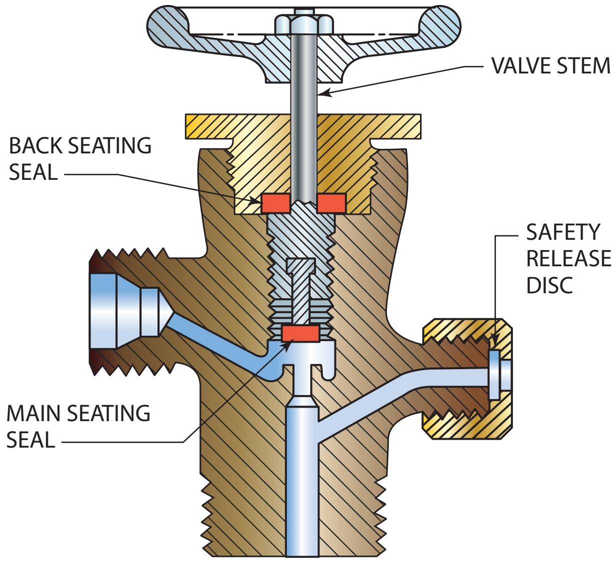

FIGURE 31-75 Cutaway of an oxygen cylinder valve showing the two separate seals. The back seating seal prevents leakage around the valve stem when the valve is open.

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FIGURE 31-73 Back out both regulator adjusting screws before opening the cylinder valve.

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FIGURE 31-76 Open the cylinder valve slowly.

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FIGURE 31-74 Stand to one side when opening the cylinder valve.

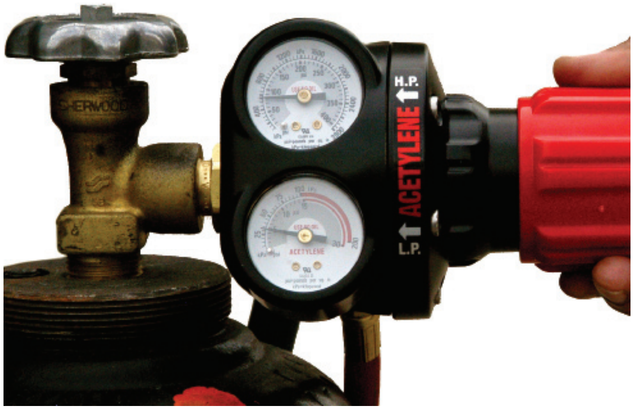
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FIGURE 31-77 Adjust the regulator to read 5 psig (35 kPag) working pressure.

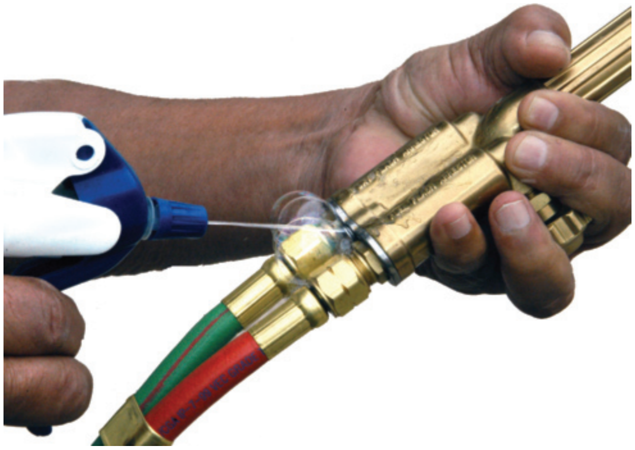
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FIGURE 31-78 Spray fittings with a leak-detecting solution.

CAUTION

If the valve is opened quickly, the regulator or gauge may be damaged, or the gauge may explode.

CAUTION

The acetylene valve should never be opened more than one and one-half turns so that in an emergency it can be turned off quickly.

CAUTION

Connections should not be overtightened. If they do not seal properly, repair or replace them.

FIGURE 31-79 Identify any cylinder that has a problem by marking it.

CAUTION

Leaking cylinder valve stems should not be repaired. Turn off the valve, disconnect the cylinder, mark the cylinder, move it outdoors or to a very well-ventilated area, and notify the supplier to come and pick up the bad cylinder, **Figure 31-79.**

The assembled oxyfuel welding equipment is now tested and ready to be ignited and adjusted.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 31-3

Lighting and Adjusting an Oxyacetylene Flame

Using the assembled and tested oxyfuel welding equipment from Practice 31-2, a **spark lighter**, gas welding goggles, gloves, and proper protective clothing, you will light and adjust an oxyacetylene torch for welding.

1. Wearing proper clothing, gloves, and gas welding goggles, turn both regulator adjusting screws in until the working pressure gauges read 5 psig (35 kPag). If you mistakenly turn on more than 5 psig (35 kPag), open the torch valve to allow the pressure to drop as the adjusting screw is turned outward.
2. Turn on the torch fuel-gas valve just enough so that some gas escapes.
3. Using a spark lighter, light the torch. Hold the lighter near the end, **Figure 31-80**, of the tip but not covering the end, **Figure 31-81**.
4. With the torch lit, increase the flow of acetylene until the flame stops smoking.

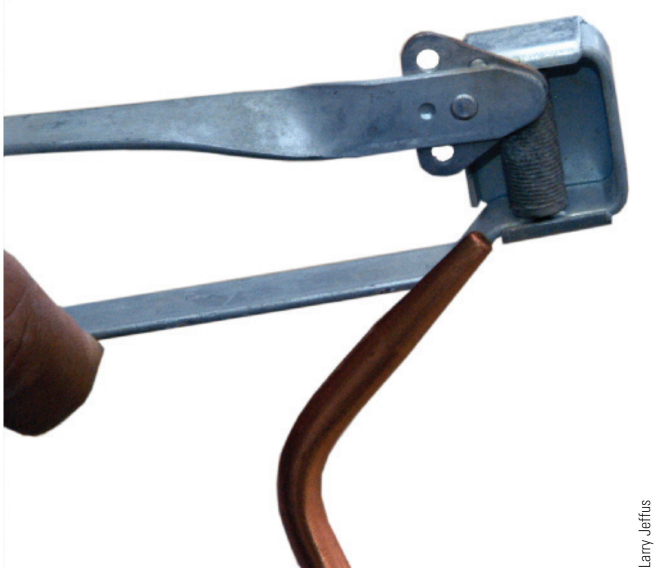


FIGURE 31-80 Correct position to hold a sparklighter.

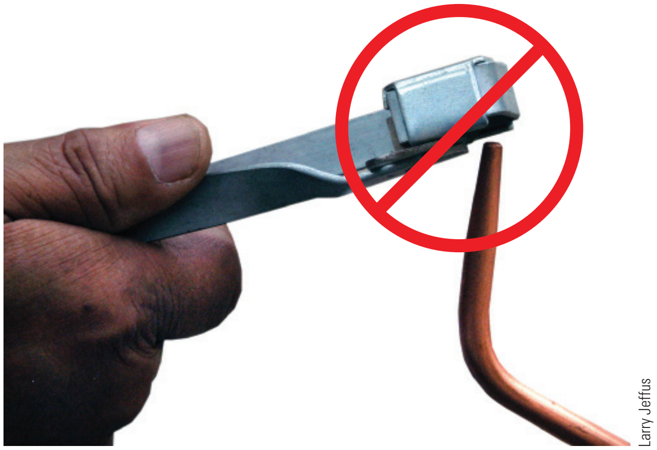


FIGURE 31-81 Sparklighter held too close over the end of the tip.

5. Slowly turn on the oxygen and adjust the torch to a neutral flame.

CAUTION

Be sure the torch is pointed away from any sources of ignition or any object or person that might be damaged or harmed by the flame when it is lit.

CAUTION

A spark lighter is the only safe device to use when lighting any torch.

This flame setting uses the minimum gas flow rate for this specific tip. The fuel flow should never be adjusted to a rate below the point where the smoke stops. This is the minimum flow rate at which the cool gases will pull the flame heat out of the tip, **Figure 31-82**. If excessive heat is allowed to build up in a tip, it can cause a backfire or flashback.

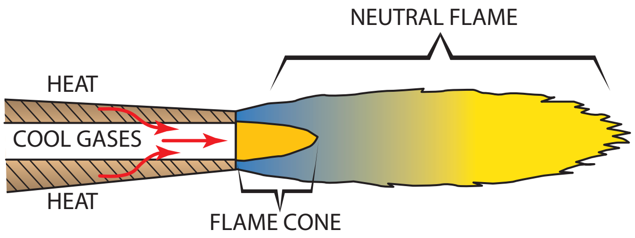


FIGURE 31-82 Enough cool gas flowing through the tip will help prevent popping.

The maximum gas flow rate gives a flame enough flow so that, when adjusted to the neutral setting, it does not settle back on the tip. This will help keep the tip cooler so it is less likely to backfire.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 31-4

Shutting Off and Disassembling Oxyfuel Welding Equipment

Using the properly lit and adjusted torch from Practice 31-3 and a wrench, you will extinguish the flame and disassemble the torch set.

1. First, quickly turn off the torch fuel-gas valve. This action blows the flame out and away from the tip, ensuring that the fire is out. In addition, it prevents the flame from burning back inside the torch. On large tips or hot tips, turning the fuel off first may cause the tip to pop. The pop is caused by a lean fuel mixture in the tip.

   If you find that the tip pops each time you turn the fuel off first, turn the oxygen off first to prevent the pop. Be sure that the flame is out before putting the torch down.
2. After the flame is out, turn off the oxygen valve.
3. Turn off the cylinder valves.
4. Open one torch valve at a time to bleed off the pressure.
5. When all of the pressure is released from the system, close both torch valves and back out both regulator adjusting screws until they are loose.
6. Loosen both ends of both hoses and unscrew them.
7. Loosen both regulators and unscrew them from the cylinder valves.
8. Replace the valve protection caps.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

Summary

The wide variety of fuel gases available for oxyfuel welding, cutting, and brazing has offered welders some unique challenges in determining the most appropriate fuel gas for their processes. Although acetylene and oxygen are the most common, acetylene is not always the most appropriate gas for a number of reasons, primarily cost. When treated properly, the waste product from acetylene production has little or no environmental impact, but such treatments can be expensive. This significantly increases the cost of acetylene and has made other fuel gases more desirable. Other fuel gases do not have all of the characteristics of acetylene. Each gas has unique advantages and disadvantages. You must look at the advantages and disadvantages of all the gases before selecting the fuel gas that will be most appropriate for your applications.

Filler metal selection for the oxyfuel welding processes used in a home hobby application is not often given much thought. In industrial applications, the proper selection of an oxyfuel filler metal is critical to the success of your product.

Always follow the equipment manufacturer's setup and operation guidelines as listed in the owner's manual. If the owner's manual is not available, copies can be obtained from the manufacturer or from their website.

Review

1. What is the purpose of a pressure regulator?
2. What may result if a pressure regulator is not used on the type of gas or pressure range for which it was designed?
3. Describe how a single-stage regulator operates.
4. Is the torch pressure always the same as the working gauge pressure? Why or why not?
5. Why does the high-pressure gauge on a regulator not always indicate the amount of gas in the cylinder?
6. How does the operation of a safety release valve differ from the operation of a safety disc valve?
7. Describe the difference between an argon cylinder valve fitting and a carbon dioxide cylinder valve fitting.
8. What is meant by *regulator creep?*
9. Who can repair regulators?
10. Why must the pressure be released from a regulator when work is finished?
11. Why are combination welding and cutting torches considered to be more versatile?
12. What is the advantage of using an injector-type mixing chamber?
13. What should be done to the valve packing if the valve knob does not turn freely after it has been tightened to stop a leak?
14. What may happen to a tip seat if it is incorrectly tightened?
15. What can happen to a tip if it is excessively cleaned with a tip cleaner?
16. What is the difference between a reverse flow valve and a flashback arrestor?
17. What are Siamese hoses?
18. Why must the pressure be bled off hoses when work is complete?
19. What is the difference between a backfire and a flashback?
20. Why is a neutral flame the most commonly used oxyacetylene flame used?
21. What properties should a good leak-detecting solution have?
22. Why must the oxygen cylinder valve be opened all the way to the top?
23. How long should hoses be purged?
24. What should be done with cylinders that have leaking valve stems?
25. How should the spark lighter be held to light a torch?
26. Once the torch is lit, why must the acetylene flow be increased until the flame stops smoking before the oxygen is turned on for adjustment?
27. What type of piping can be used for a manifold system?
28. What elements make up all hydrocarbons?
29. What are the separate parts that make up an oxyacetylene flame?
30. Use Table 31-3 to determine which fuel gas requires the largest amount of oxygen from the torch.

31. Approximately how long would it take a 50/50 mixture of oxygen and acetylene to flash back through a 21-ft- (7.62-m) long hose?
32. Use Table 31-4 to determine which fuel gas has the highest burning velocity when mixed with oxygen.
33. How is acetylene produced?
34. Why is it not safe to use acetylene above 15 psig (100 kPag)?
35. Use Table 31-5 to determine the largest tip orifice size (drill number) that could be used with an acetylene cylinder containing 175 cu ft (4956 L).
36. Where is the highest temperature and where is the greatest heat produced in a neutral oxyacetylene flame?
37. Use Table 31-6 to determine what would be the pressures in cylinders containing: (a) MAPP®, (b) propane, and (c) ethane on a 100°F (38°C) day.
38. What are methylacetylene-propadiene fuel gases used for?
39. Use Table 31-7 to determine which oxygen fuel-gas mixture produces the highest total heat.
40. Which fuel gas has the strongest odor and is easiest to detect?
41. What is the major advantage of using propane or natural gas?
42. Use Table 31-8 to determine which fuel gas would be best for (a) cutting material thicker than 5 in. (125 mm), (b) powdered metallizing, and (c) stack cutting.
43. What two major safety problems does hydrogen present?
44. Why should coat hangers not be used as gas welding filler metal?
45. Explain the significance of the AWS filler metal classification RG45.

Chapter 32
Oxyacetylene Welding

OBJECTIVES

After completing this chapter, the student should be able to

- explain how to set up and weld mild steel.
- make a variety of welded joints in any position on thin-gauge, mild steel sheet.
- make a satisfactory weld on small-diameter pipe and tubing in any position.
- explain the effects of torch angle, flame height, filler metal size, and welding speed on gas welds.

KEY TERMS

1G position	*keyhole*	*shelf*
2G position	*kindling point*	*tee joint*
5G position	*lap joint*	*torch angle*
6G position	*molten weld pool*	*torch manipulation*
burnthrough	*out-of-position welding*	*trailing edge*
flashing	*outside corner joint*	*undercut*
flat butt joint	*overhead weld*	*vertical weld*
heat sink	*overlap*	*weld crater*
horizontal welds	*penetration*	

INTRODUCTION

Oxyacetylene welding is limited to thin metal sections or to times when portability is important. During the early years of welding, oxyacetylene was used to weld thick plate of 1 in. (25 mm) or thicker. Today, it is used almost exclusively on thin metal of 11 gauge or thinner. One of the arc welding processes is most often used today for welding metal thicker than 16 gauge. Some of the arc welding processes, such as GMAW, are replacing the gas welding processes on metals of 28 gauge and thinner, **Figure 32-1**. Because of the expanded use of arc welding processes on thinner sections, we concentrate on the use of gas welding on metal having a thickness of 16 gauge (approximately 1/16 in. [2 mm]) or thinner.

FIGURE 32-1 Gas metal arc welded (GMAW) on 16-gauge mild steel.

MILD STEEL WELDS

Mild steel is the easiest metal to gas weld. With this metal, it is possible to make welds with 100% integrity (lack of porosity, oxides, or other defects) and that have excellent strength, good ductility, and other positive characteristics. The secondary flame shields the molten weld pool from the air, which would cause oxidation. The atmospheric oxygen combines with the carbon monoxide (CO) from the outer flame envelope to produce carbon dioxide (CO_2). The carbon dioxide will not react with the molten weld pool. In addition, the carbon dioxide forces the surrounding atmosphere away from the weld.

Factors Affecting the Weld

Torch Tip Size The torch tip size should be used to control the weld bead width, penetration, and speed. **Penetration** is the depth into the base metal that the weld fusion or melting extends from the surface, excluding any reinforcement. Because each tip size has a limited operating range in which it can be used, tip sizes must be changed to suit the thickness and size of the metal being welded. Never reduce the flame size if the torch tip is too large if the correct tip size is unavailable. When the flame size or volume is lowered below the correct settings for the tip by lowering the gas flow, the tip will overheat. If the flame is lowered significantly, then the tip can overheat even without using it to weld. Overheated tips will backfire. Backfiring can cause dangerous flashback. Other factors that can be changed to control the weld size are the torch angle, the flame-to-metal distance, the welding rod size, and the way the torch is manipulated.

CAUTION

It is never safe to lower the flame size if the tip's flame produces too much heat for your welding job. Get a smaller tip or change your welding technique.

Torch Angle The **torch angle** and the angle between the inner cone and the metal have a great effect on the speed of melting and size of the molten weld pool. The ideal angle for the welding torch is 45°. As this angle increases toward 90°, the rate of heating increases. As the angle decreases toward 0° to the plate's surface, the rate of heating decreases, as illustrated in **Figure 32-2**. The distance between the inner cone and the metal ideally should be 1/8 in. to 1/4 in. (3 mm to 6 mm). As this distance increases, the rate of heating decreases; as the distance decreases, the heating rate increases, **Figure 32-3**.

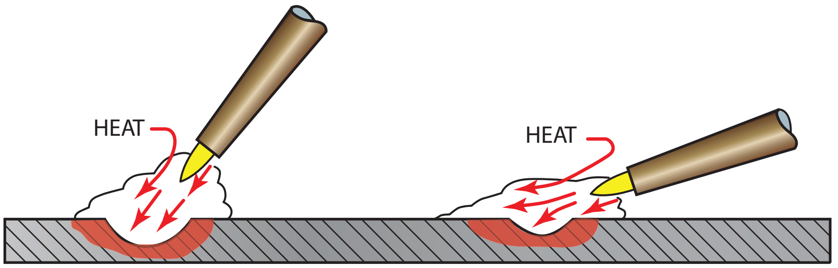


FIGURE 32-2 Changing the torch angle changes the percentage of heat that is transferred into the metal.

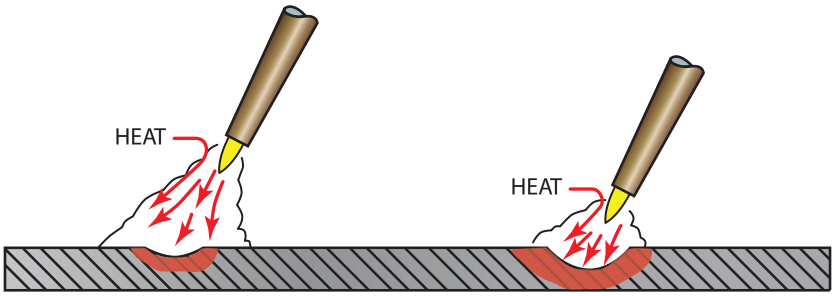
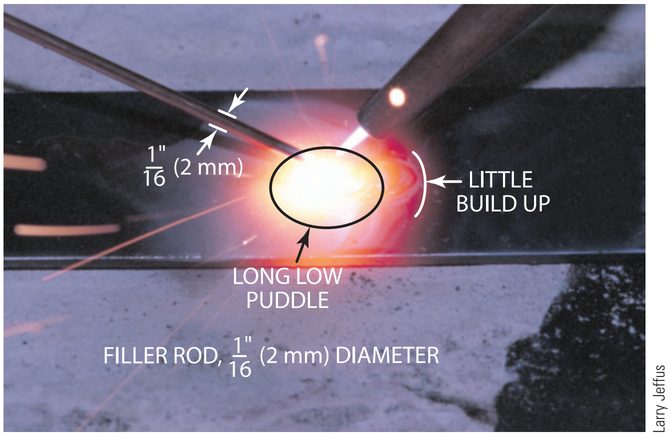
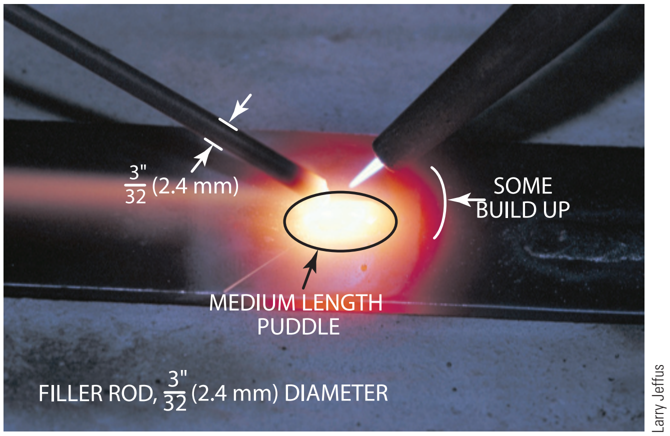


FIGURE 32-3 Changing the distance between the torch tip and the metal changes the percentage of heat input into the metal.

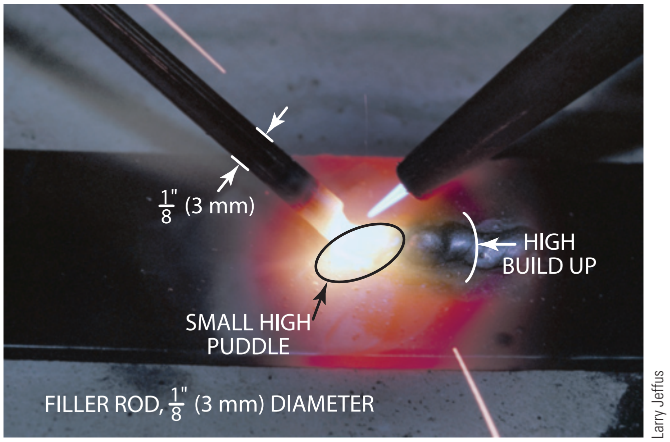
Welding Rod Size Welding rod size and **torch manipulation** can be used to control the weld bead characteristics. A larger welding rod can be used to cool the molten weld pool, increase buildup, and reduce penetration, **Figure 32-4A**, **B**, and **C**. The torch can be manipulated so that the direct heat from the flame is flashed off the molten weld pool for a moment to allow it to cool, **Figure 32-5**.



(A)



(B)



(C)

FIGURE 32-4 If all other conditions remain the same, changing the size of the filler rod will affect the weld as shown in (A), (B), and (C).

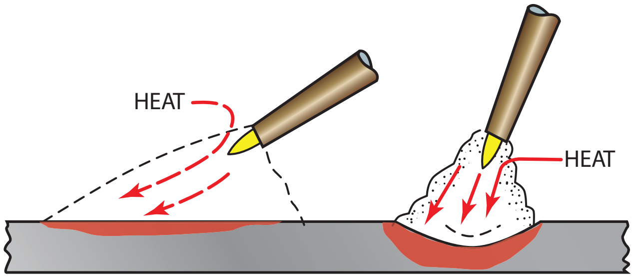


FIGURE 32-5 Flashing the flame off the metal will allow the molten weld pool to cool and reduce in size.

CHARACTERISTICS OF THE WELD

The **molten weld pool** must be protected by the secondary flame to prevent the atmosphere from contaminating the metal. If the secondary flame is suddenly moved away from a molten weld pool, then the pool will throw off a large number of sparks. These sparks are caused by the rapid burning of the metal and its alloys as they come into contact with oxygen in the air. This is particularly a problem when a weld is stopped. The **weld crater** is especially susceptible to cracking if the molten weld pool is allowed to burn out, **Figure 32-6**. To prevent burnout, the torch should be raised or tilted, keeping the outer flame envelope over the molten weld pool until it solidifies. As the molten weld pool is being cooled, the molten weld pool should also be filled with welding rod so that it is a uniform height compared to the surrounding weld bead.

The sparks that occur as the weld progresses are due to metal components that are being burned out of the weldment. Silicon oxides make up most of the sparks, and extra silicon can be added by the filler metal so that the weldment retains its desired soundness. A change in the number of sparks given off by the weld as it progresses can be used as an indication of changes in weld temperature. An increase in sparks on clean metal means an increase in weld temperature. A decrease in sparks indicates a decrease

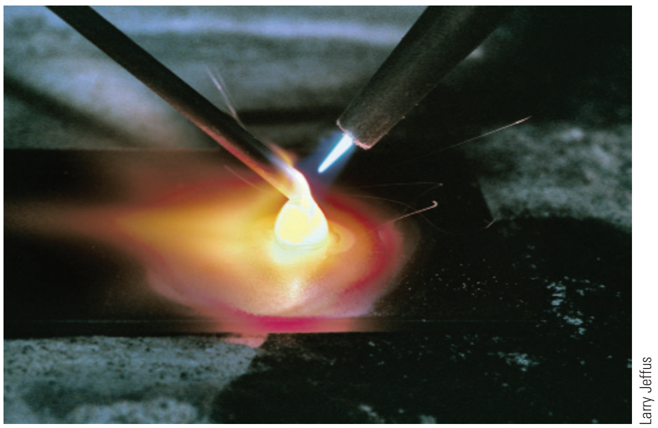


FIGURE 32-6 Building up the molten weld pool before it is ended will help prevent crater cracking.

in weld temperature. Often the number of sparks in the air increases just before a **burnthrough** takes place—that is, burning out the molten metal that appears on the back side of the plate. This burnout does not happen to molten metal until it reaches the **kindling point** (the temperature that must be attained before something begins to burn). Small amounts of total penetration usually will not cause a burnout. When the sparks increase quickly, the torch should be pulled back to allow the metal to cool and prevent a burnthrough.

EXPERIMENT 32-1

Flame Effect on Metal

The first experiment examines how the flame affects mild steel. Use a piece of 16-gauge mild steel and the proper size torch tip. Light and adjust the flame by turning down the oxygen so that the flame has excessive acetylene. Hold the flame on the metal until it melts and observe what happens, **Figure 32-7**. Now adjust the flame by turning up the oxygen so that the flame is neutral. Hold this flame on the metal until it melts and observe what takes place, **Figure 32-8**. Next, adjust the flame by turning up the oxygen so that the flame has excessive oxygen. Hold this flame on the metal until it melts and observe what happens, **Figure 32-9**. Repeat this experiment until you can easily identify each of the three flame settings by the flame, molten weld pool, sound, and sparks.

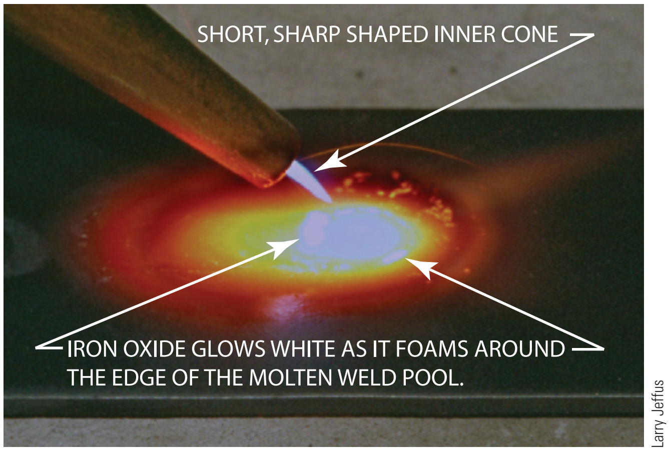


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FIGURE 32-9 Oxidizing flame (excessive oxygen).

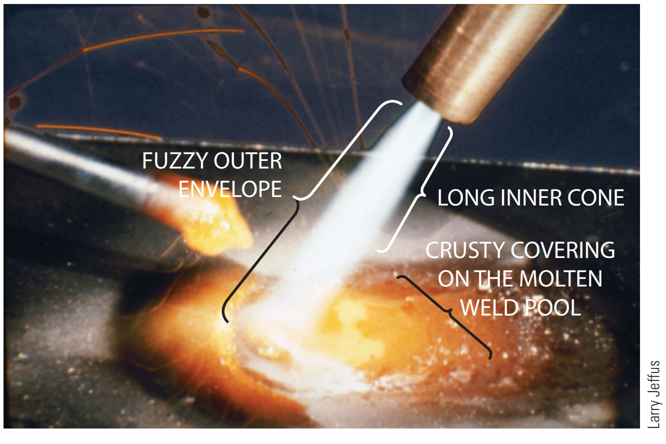

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FIGURE 32-7 Carbonizing flame (excessive acetylene).

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FIGURE 32-8 Neutral flame (balanced oxygen and acetylene).

Before actual welding is started, it is a good idea to find a comfortable position. The more comfortable or relaxed you are, the easier it will be for you to make uniform welds. The angle of the plate to you and the direction of travel are important.

Place a plate on the table in front of you and, with the torch off, practice moving the torch in one of the suggested patterns along a straight line, as illustrated in **Figure 32-10**. Turn the plate and repeat this step until you determine the most comfortable direction of travel. Later, when you have mastered several joints, you should change this angle and try to weld in a less comfortable position. Welding in the field or shop must often be done in positions that are less than comfortable, so the welder needs to be somewhat versatile.

It is important to feed the welding wire into the molten weld pool at a uniform rate. **Figure 32-11A** and **B** show some suggested methods of feeding the wire by hand. It is also suggested that you not cut the welding wire into two pieces for welding. Short lengths are easy to use, but this practice often results in wasted filler metal. The end of the welding wire may be rested on your shoulder so that it is easy to handle.

CAUTION

The end of the filler rod should have a hook bent in it so that you can readily tell which end may be hot and so that the sharp end will not be a hazard to a welder who is working next to you, **Figure 32-12**.

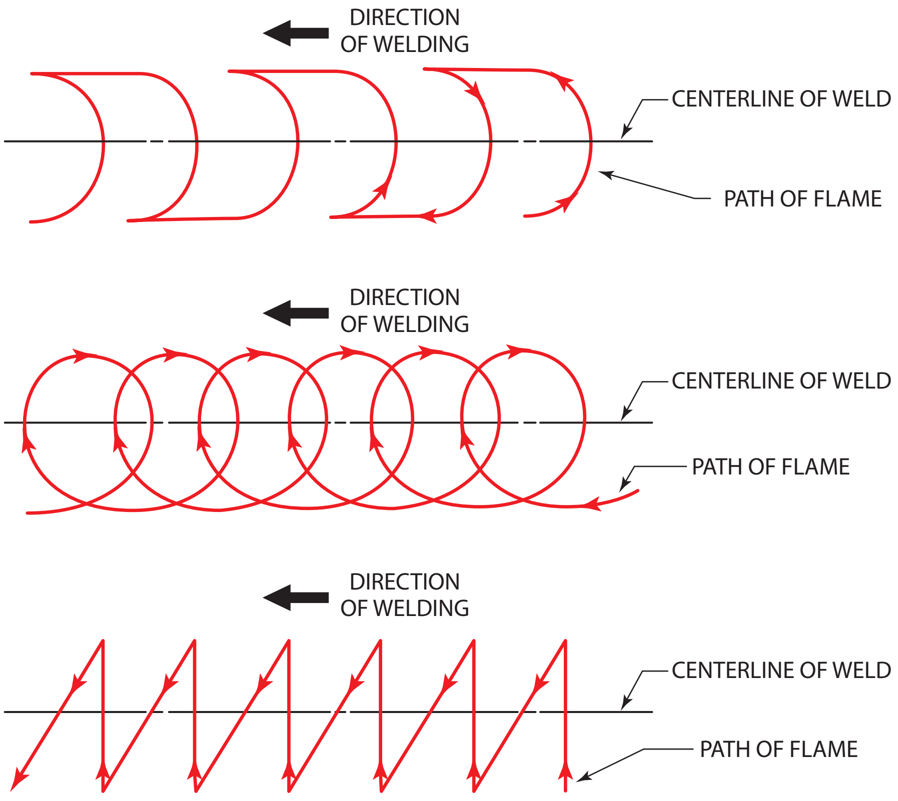

FIGURE 32-10 A few torch patterns.

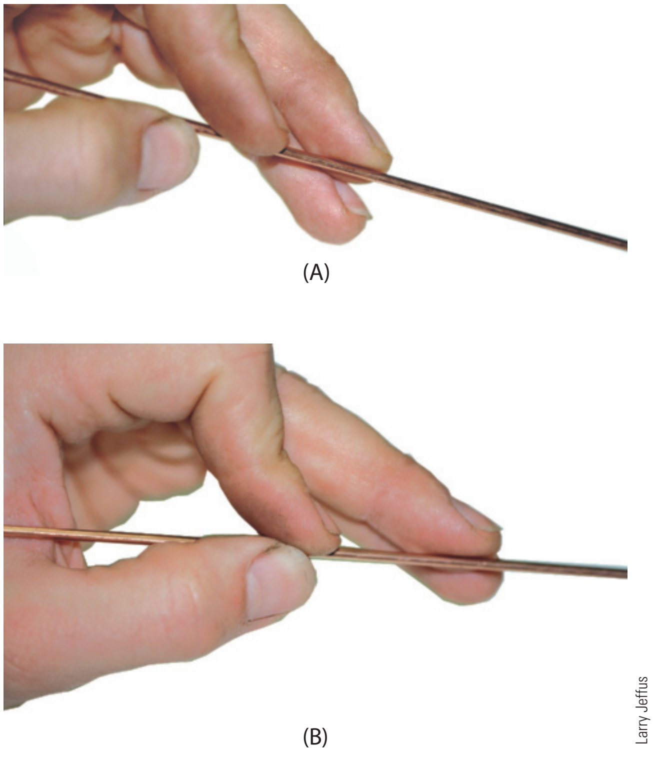

FIGURE 32-11 (A) Feed the filler rod by using your index finger. (B) Move your finger back each time to be ready to feed the filler wire again.

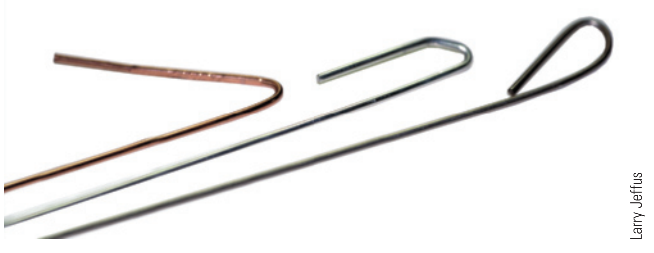

FIGURE 32-12 The end of the filler rod should be bent for safety and easy identification.

The torch hoses may be stiff and may therefore cause the torch to twist. Before you start welding, move the hoses so that there is no twisting of the torch. This will make the torch easier to manipulate and will be more relaxing for you.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 32-1

Pushing a Molten Weld Pool

Using a clean piece of 16-gauge mild steel sheet, approximately 6 in. (152 mm) long, and a torch that is lit and adjusted

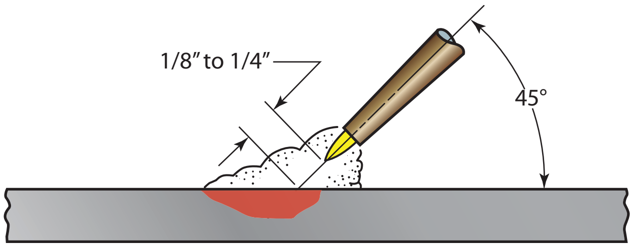

FIGURE 32-13 Hold the torch at a 45° angle in the direction of the weld.

to a neutral flame, push a molten weld pool in a straight line down the sheet. Start at one end and hold the torch at a 45° angle in the direction of the weld, **Figure 32-13**. When the metal starts to melt, move the torch in a circular pattern down the sheet toward the other end. If the size of the molten weld pool changes, speed up or slow down to keep it the same size all the way down the sheet, **Figure 32-14**. Repeat this practice until you can keep the width of the molten weld pool uniform and the direction of travel in a straight line.

Uniformity in width shows that you have control of the molten weld pool. A straight line indicates that you can see more than the molten weld pool itself. Students just learning to weld usually see only the molten weld pool. As you master the technique of welding, your visual range will increase. A broad visual range is important so that later you will be able to follow the joint, watch for distortion or see if other adjustments are needed, and relax as you weld. Turn off the cylinders, bleed the hoses, back out the regulator adjusting screws, and clean your work area when you are finished.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

EXPERIMENT 32-2

Effect of Torch Angle and Torch Height Changes

Use a clean piece of 16-gauge mild steel and a torch adjusted to a neutral flame. You will be experimenting with different torch angles and torch heights to change the size of the molten weld pool, **Figure 32-15**.

To start this experiment, hold the torch at a 45° angle to the metal with the inner cone at approximately 1/8 in. (3 mm) above the metal surface, **Figure 32-16A**, **B**, and **C**. As the metal starts to melt, move the torch slowly down the sheet. As you move, increase and decrease the angle of the torch to the sheet and observe the change in the size of the molten weld pool. Repeat the experiment, but this time as you move down the sheet, raise and lower the torch and observe the effect on the size of the molten weld pool.

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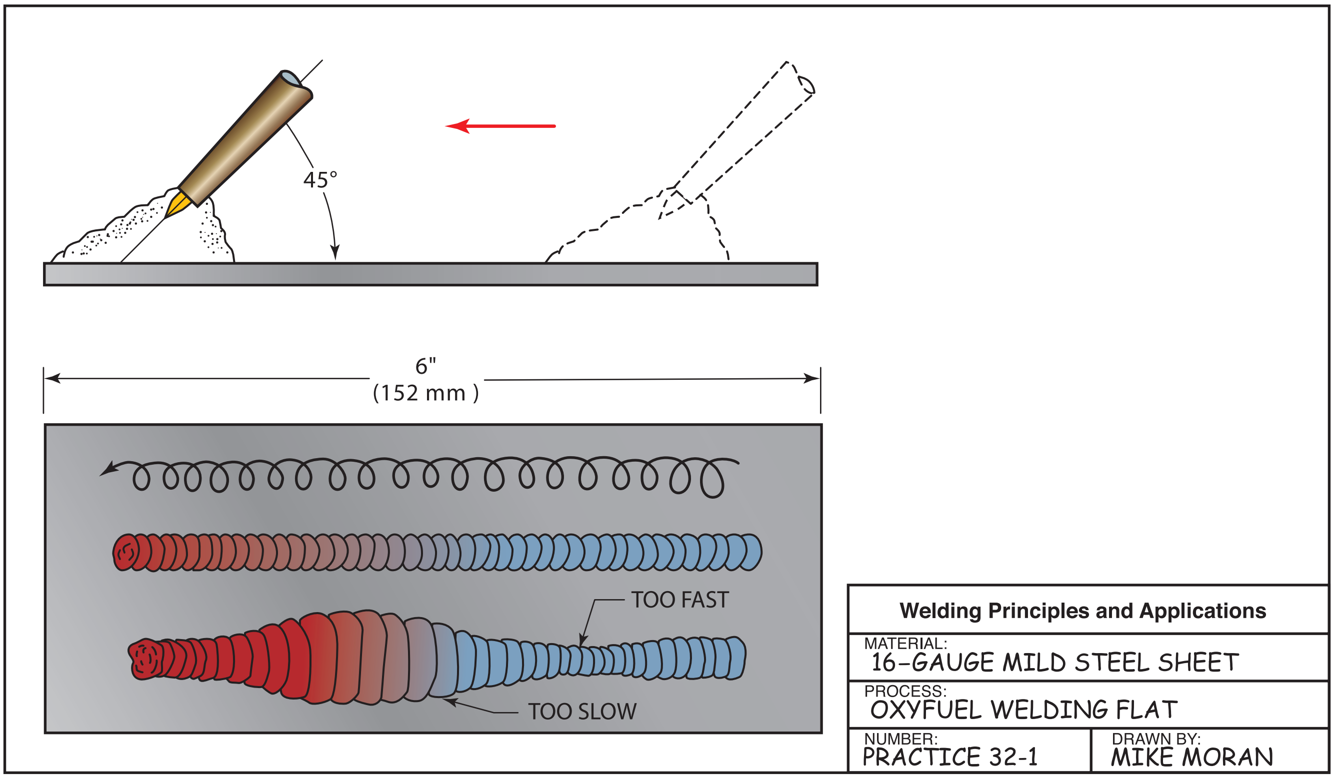

FIGURE 32-14 Effect of changing the rate of travel.

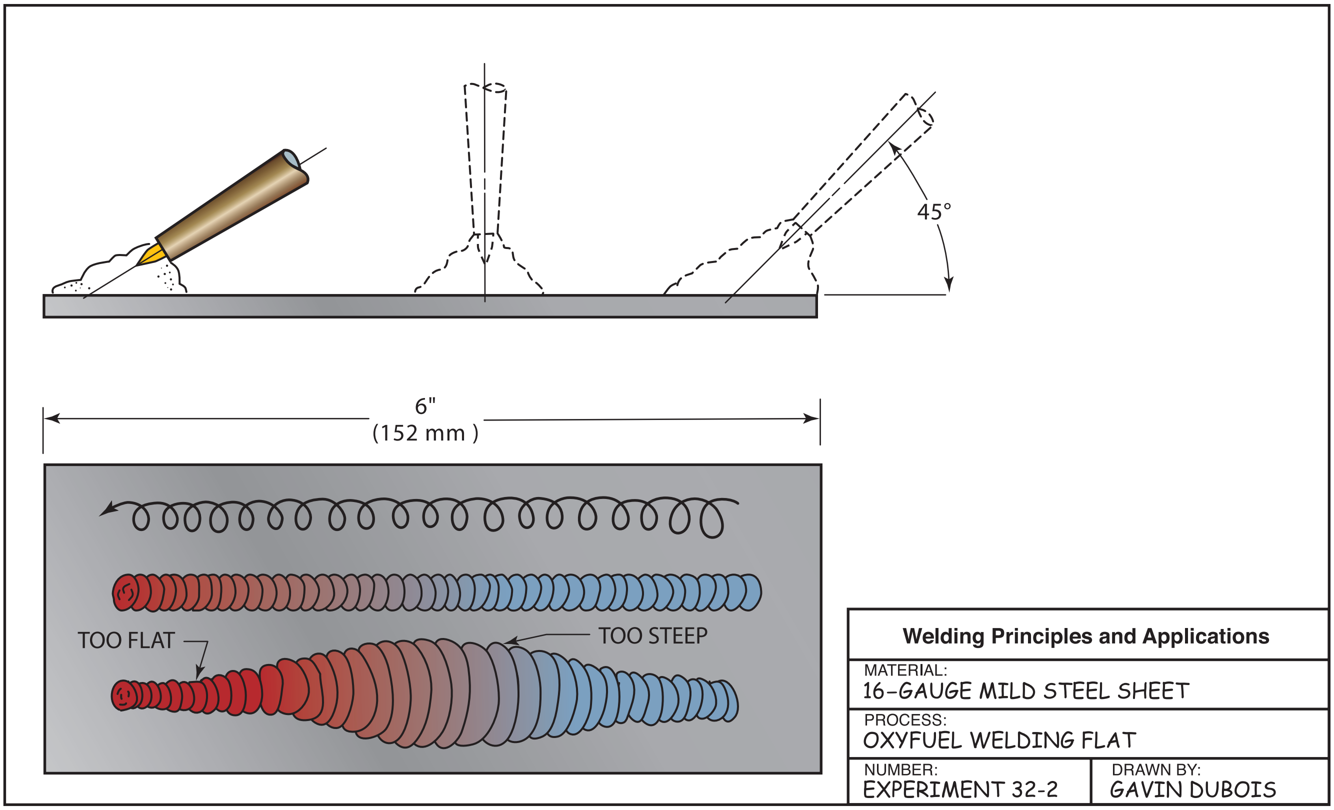

FIGURE 32-15 Effect of changing torch angle.

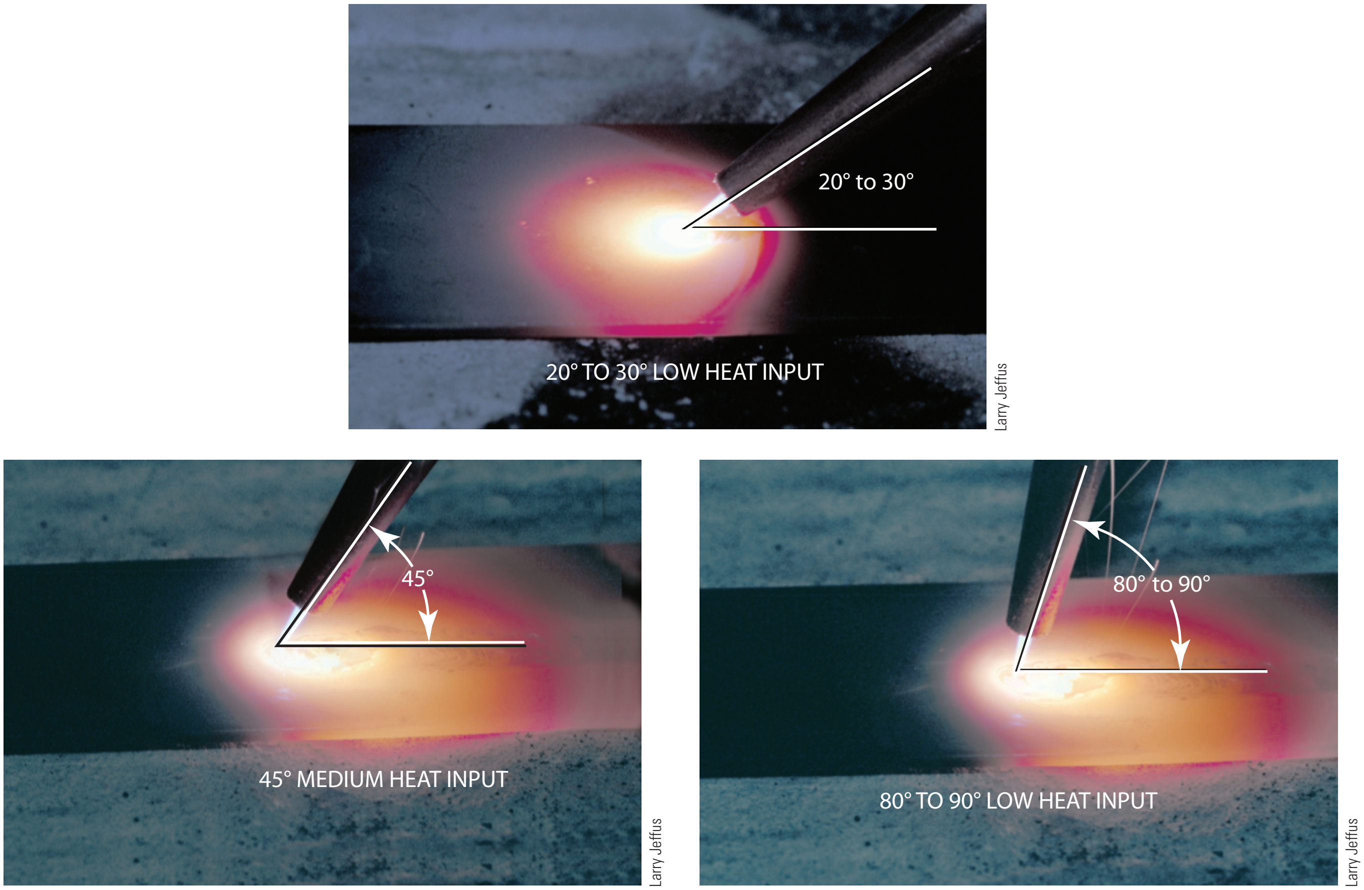

FIGURE 32-16 Changes in the angle between the torch and the work will change the molten weld pool produced.

PRACTICE 32-2

Beading

Repeat Experiment 32-2 until you can control the change in the size of the molten weld pool, as shown in **Figure 32-17**. After the control of the molten weld pool has been mastered, you are ready to start adding filler rod. When selecting and adding filler metal, the following are some facts to remember.

Selecting the proper size or correct diameter of filler metal will help control the weld bead width, buildup, and penetration. A large-diameter filler rod can be used as a **heat sink** (something to draw off excessive heat) to keep the molten weld pool narrow, with little penetration and high buildup. As the diameter of the filler wire is decreased, the heat-absorbing effect decreases, and the molten weld pool becomes wider, with deeper penetration and reduced buildup. On thin metal, it may be necessary to use a large-diameter filler rod to control burnthrough. On thick metal, a small-diameter filler rod may be used to increase penetration.

Another thing to remember when adding filler metal to a weld is to keep a smooth and uniform rhythm. Each weld joint has its own indicator that will tell you when to add welding rod, **Figure 32-18**. As a new welder, watch for these indicators and try to anticipate adding the rod so that the indicators do not appear. At the end of a joint, it may be necessary to apply the welding rod faster and cool the molten weld pool to keep the weld bead uniform.

The end of the welding rod should always be kept inside the protective envelope of the flame, **Figure 32-19**. The hot end of the welding rod oxidizes each time it is removed from the protection of the flame. This oxide is deposited in the molten weld pool, causing sparks and a weak or brittle weld.

When the rod is added to the molten weld pool, the flame can be moved back as the end of the rod is dipped into the leading edge of the molten weld pool, **Figure 32-20**. If the torch is not moved back, then the rod may melt and drip into the molten weld pool; this is an incorrect way of adding filler metal, **Figure 32-21**. The major problems with adding rod in this manner are: (1) the drop of metal tends to overheat, resulting in important alloys being

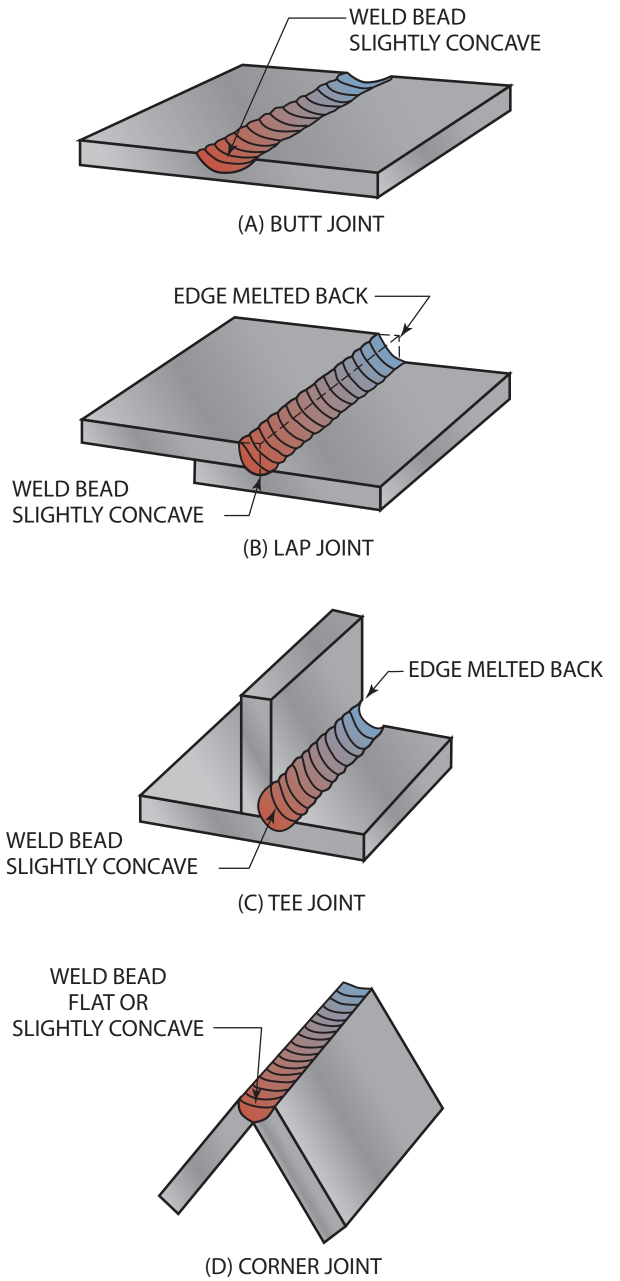

FIGURE 32-18 Indications that more filler metal should have been added. (A) Butt joint. (B) Lap joint. (C) Tee joint. (D) Corner joint.

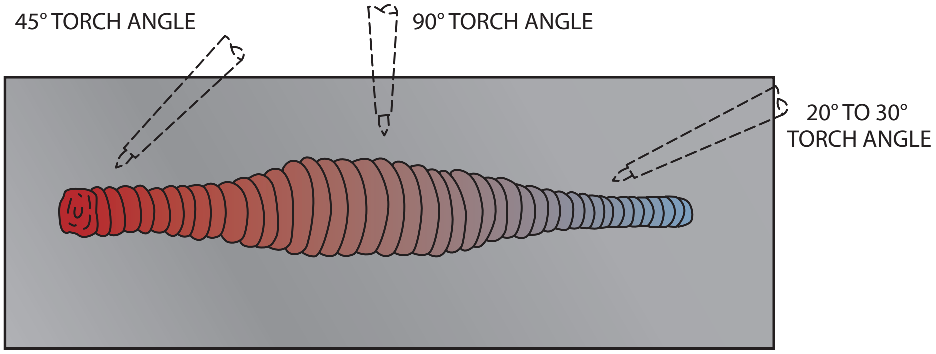

FIGURE 32-17 Changing the weld bead size by changing the torch angle.

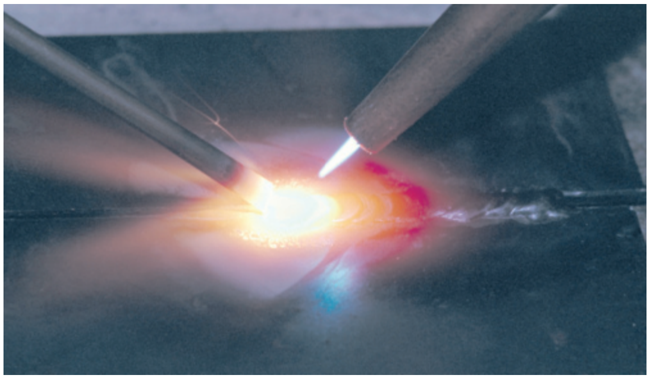

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FIGURE 32-19 The hot end of the filler rod is protected from the atmosphere by the outer flame envelope.

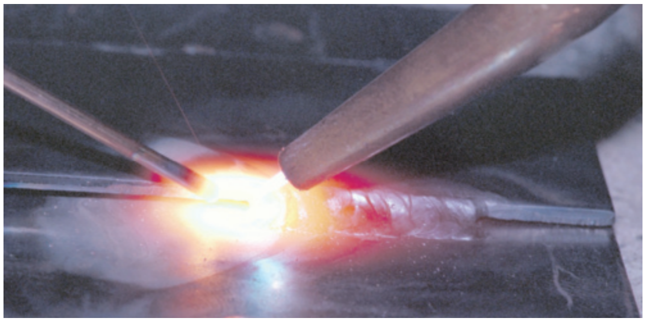

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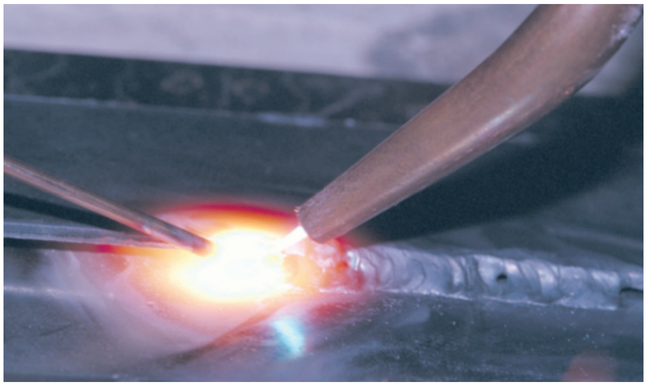
FIGURE 32-20 Filler metal being correctly added by dipping the rod into the leading edge of the molten weld pool.



Larry Jeffus

FIGURE 32-21 Filler metal being incorrectly added by allowing the rod to melt and drip into the molten weld pool.

burned out; (2) the metal cannot always be added where it is needed; and (3) the method works only in the flat position. When dipping the rod into the molten weld pool, if the rod touches the hot metal around the molten weld pool, it will stick. When this happens, move the flame directly to the end of the rod to melt and free it. Turn off the cylinders, bleed the hoses, back out the regulator adjusting screws, and clean your work area when you are finished.

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EXPERIMENT 32-3

Effect of Rod Size on the Molten Weld Pool

Use a properly lit and adjusted torch, 6 in. (152 mm) of 16-gauge mild steel, and three different diameters of RG45 gas welding rods 1/8 in. (3 mm), 3/32 in. (2.4 mm), and 1/16 in. (2 mm) by 36 in. (914 mm) long. In this experiment, you will observe the effect on the molten weld pool of changing the size of filler metal. You also will practice adding the filler metal to the molten weld pool.

Starting with the 1/8-in. (3-mm) filler metal, make a weld 6 in. (152 mm) long. Next to this weld, make another one with the 3/32-in. (2.4-mm) rod, and then one with the 1/16-in. (2-mm) rod. Try to keep the angle, speed, height, and pattern of the torch the same during each of the welds. Observe the differences in each of the weld sizes.

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PRACTICE 32-3

Stringer Bead, Flat Position

Repeat Experiment 32-3 until you have mastered a straight and uniform weld with any of the three sizes of filler rod.

Joining two or more clean pieces of metal to form a welded joint is the next step in learning to weld. The joints must be uniform in width and buildup so that they will have maximum strength. For each type of gas welded joint, the amount of penetration required to give maximum strength will vary and may not be 100%, **Figure 32-22**. For example, in thin sheet metal there is usually enough reinforcement on the weld to give the weld adequate strength. But if that reinforcement has to be removed, then 100% penetration is important, **Figure 32-23**. Some joints, such as the lap joint, may never need 100% penetration. However, they do need 100% fusion. Turn off the cylinders,

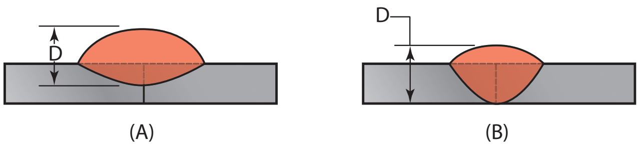

FIGURE 32-22 Welds (A) and (B) both have approximately the same strength—but only if the reinforcement does not have to be removed.

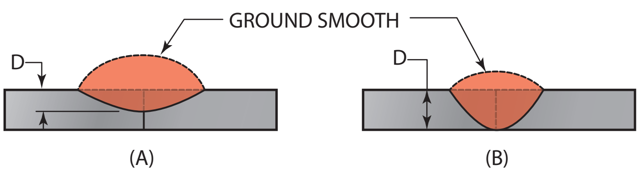

FIGURE 32-23 If the buildup on both welds is removed, weld (B) would be the stronger weld.

bleed the hoses, back out the regulator adjusting screws, and clean your work area when you are finished.

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FLAT POSITION WELDING

Outside Corner Joint

The flat **outside corner joint** can be made with or without the addition of filler metal. This joint is one of the easiest welded joints to make. If the sheets are tacked together properly, then the addition of filler metal is not needed. However, if filler metal is added, it should be added uniformly, as in the stringer beads in Practice 32-3.

PRACTICE 32-4

Outside Corner Joint, Flat Position

Using a properly lit and adjusted torch, two clean pieces of 16-gauge mild steel 6 in. (152 mm) long, and filler metal, you will make a flat outside corner welded joint, **Figure 32-24**.

Place one of the pieces of metal in a jig or on a firebrick and hold or brace the other piece of metal vertically on it, as shown in **Figure 32-25** and **Figure 32-26**. Tack the ends of the two sheets together. Then, set it upright and put two or three more tacks on the joint, **Figure 32-27**. Holding the torch as shown in **Figure 32-28**, make a uniform weld along the joint. Repeat this until the weld can be made without defects. Turn off the cylinders, bleed the hoses, back out the regulator adjusting screws, and clean your work area when you are finished.

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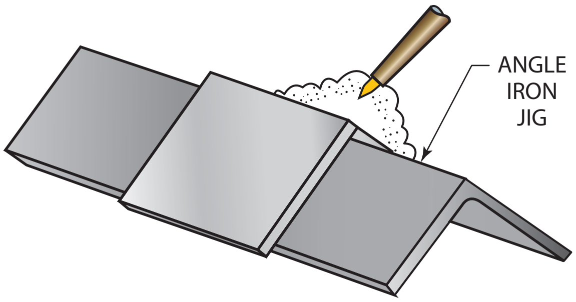

FIGURE 32-25 Angle iron jig for holding metal so it can be tack welded.

Butt Joint

The **flat butt joint** is a welded joint and is one of the easiest to make. To make the butt joint, place two clean pieces of metal flat on the table and tack weld both ends together, as illustrated in **Figure 32-29**. Tack welds may also be placed along the joint before welding begins.

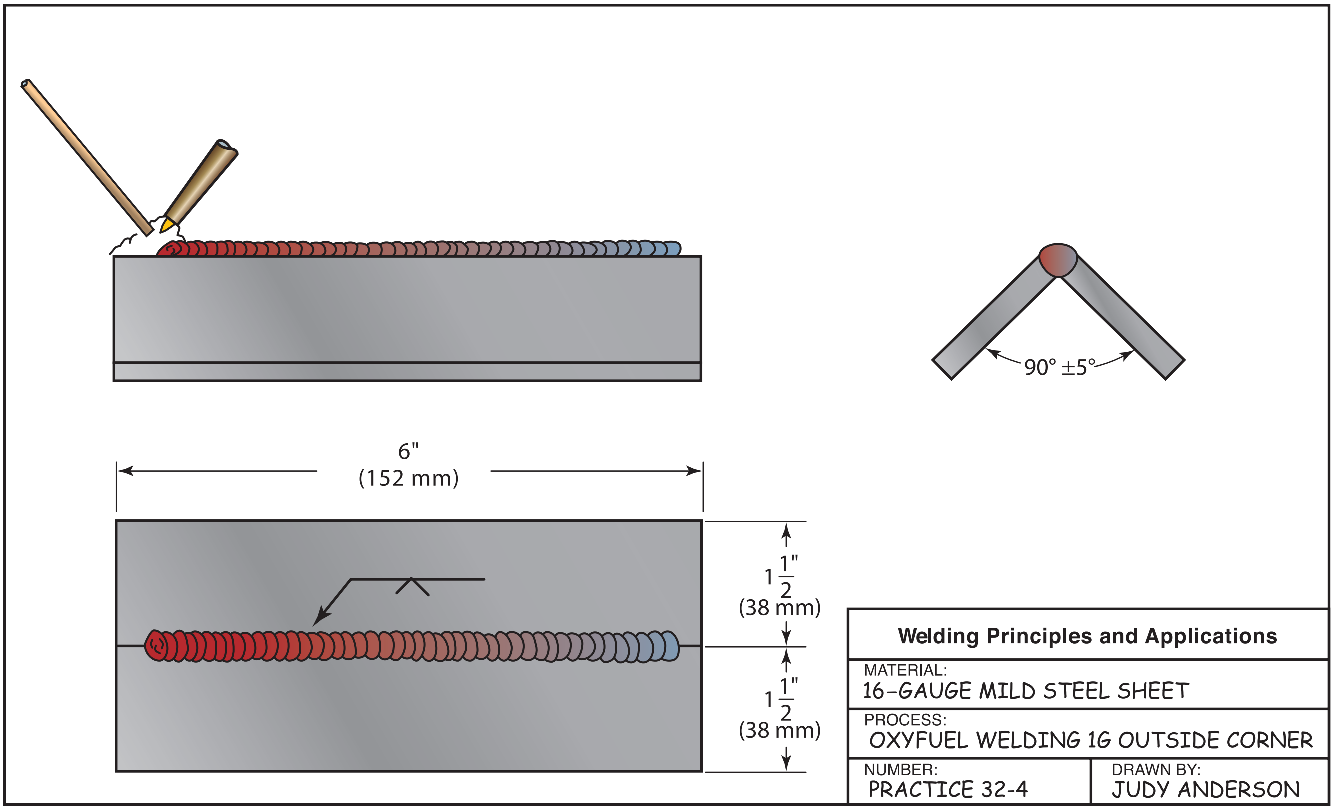

FIGURE 32-24 Outside corner.

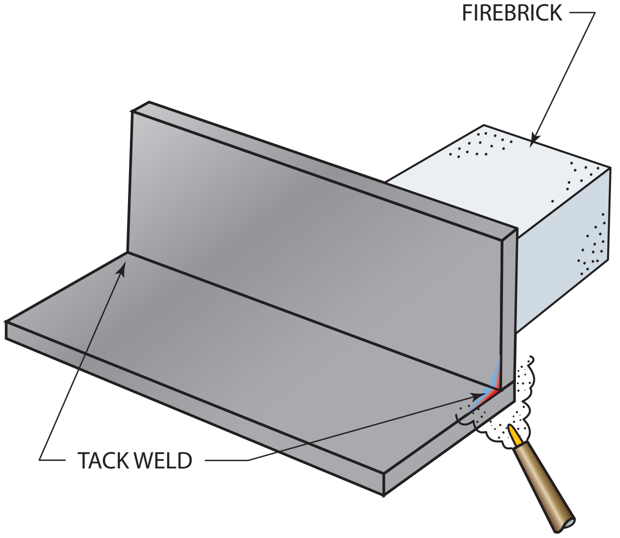

FIGURE 32-26 Tack welding the outside corner joint using a fire brick to support the metal.

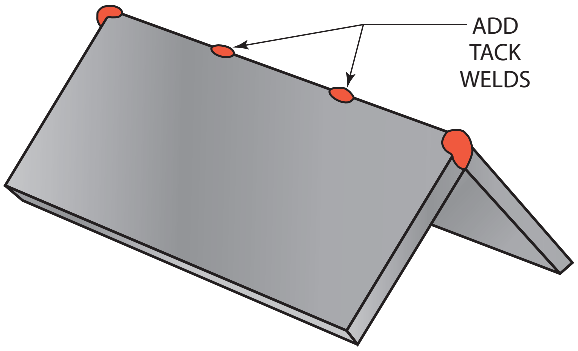

FIGURE 32-27 Tack welding.

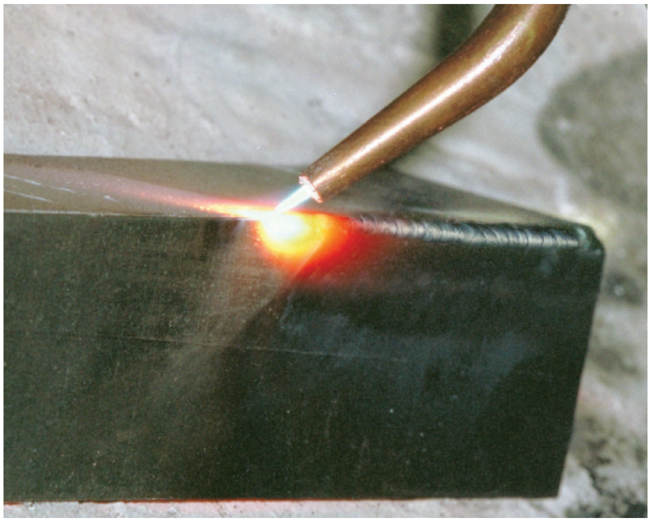

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FIGURE 32-28 Outside corner joint.

Point the torch so that the flame is distributed equally on both sheets. The flame is to be in the direction that the weld is to progress. If the sheets to be welded are of different sizes or thicknesses, then the torch should be pointed so that both pieces melt at the same time, **Figure 32-30**.

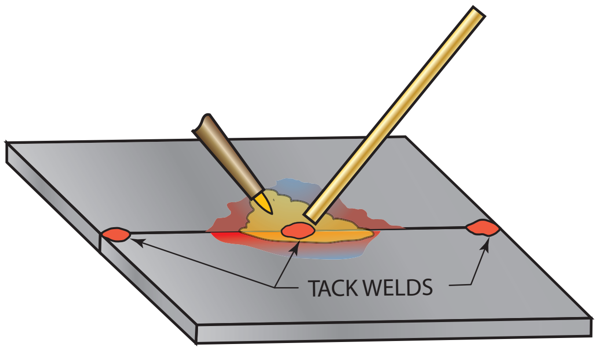

FIGURE 32-29 Making a tack weld.

When both sheet edges have melted, add the filler rod in the same manner as in Practice 32-3.

PRACTICE 32-5

Butt Joint, Flat Position

Using a properly lit and adjusted torch, two clean pieces of 16-gauge mild steel 6 in. (152 mm) long, and filler metal, you will make a welded butt joint, **Figure 32-31**.

Place the two pieces of metal in a jig or on a firebrick and tack weld both ends together. The tack on the ends can be made by simply heating the ends and allowing them to fuse together or by placing a small drop of filler metal on the sheet and heating the filler metal until it fuses to the sheet. The latter method is especially convenient if you have to use one hand to hold the sheets together and the other to hold the torch. After both ends are tacked together, place one or two small tacks along the joint to prevent warping during welding.

With the sheets tacked together, start welding from one end to the other using the technique learned in Practice 32-3. Repeat this weld until you can make a welded butt joint that is uniform in width and reinforcement and has no visual defects. The penetration of this practice weld may vary. Turn off the cylinders, bleed the hoses, back out the regulator adjusting screws, and clean your work area when you are finished.

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PRACTICE 32-6

Butt Joint with 100% Penetration

Using the same equipment, materials, and setup as described in Practice 32-5, make a welded butt joint with 100% penetration along the entire 6 in. (152 mm) of the welded joint and then visually inspect (VT) the root (back) to see if it has complete penetration. Turn off the cylinders, bleed the hoses, back out the regulator adjusting screws, and clean your work area when you are finished.

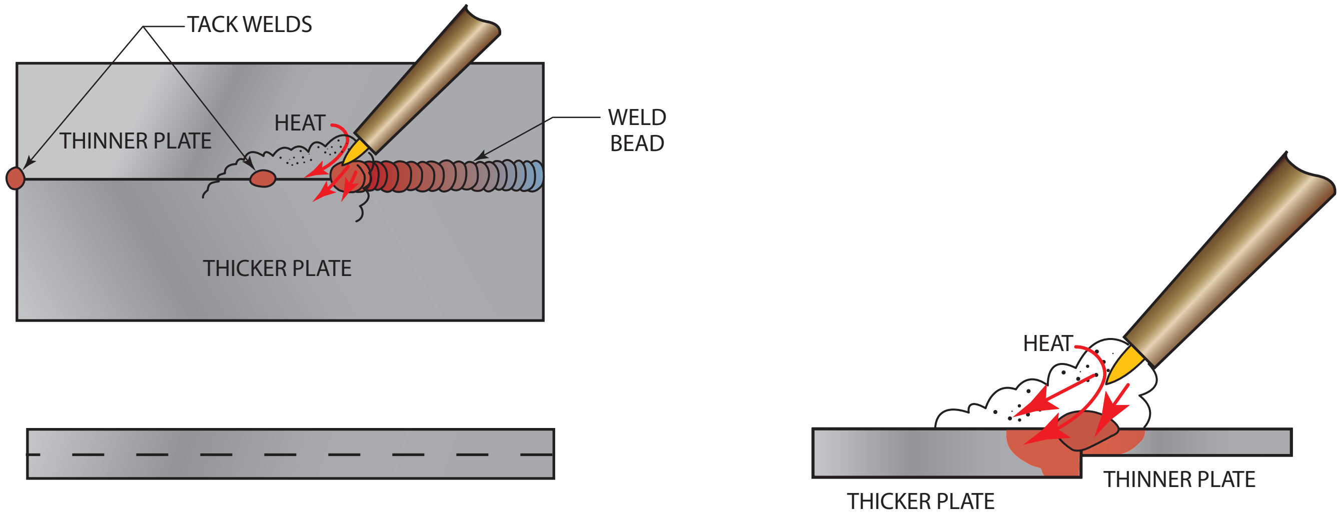

FIGURE 32-30 Direct the flame on the thicker plate.

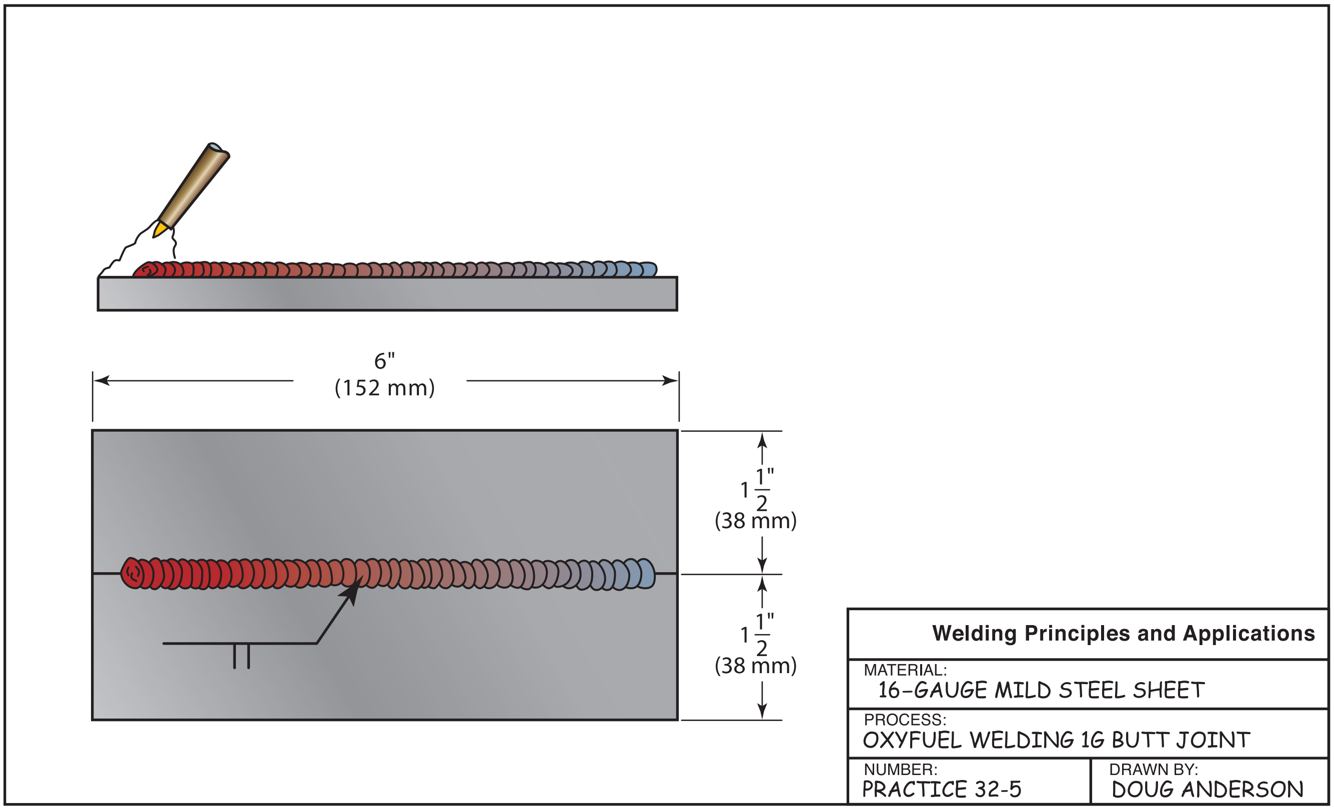

FIGURE 32-31 Butt joint.

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PRACTICE 32-7

Butt Joint with Minimum Distortion

Using a properly lit and adjusted torch, two clean pieces of 16-gauge mild steel 6 in. (152 mm) long, and filler metal, you will make a welded butt joint while controlling distortion and penetration.

Distortion can be controlled by back stepping a weld, proper tacking, and clamping. For this weld, back stepping and proper tacking will be used to control distortion. The tacking sequence to be used is shown in **Figure 32-32**. The back-stepping method to be used is illustrated in **Figure 32-33**. Back stepping will also eliminate the problem of burning away the end of the sheet. Practice this weld

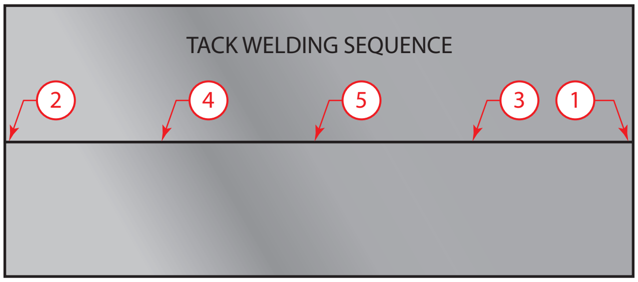


FIGURE 32-32 Tack welding sequence used to minimize distortion.

until you can pass a visual inspection (VT) for distortion. Turn off the cylinders, bleed the hoses, back out the regulator adjusting screws, and clean your work area when you are finished.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

Lap Joint

The flat **lap joint** can be easily welded if some basic manipulations are used. When heating the two clean sheets, caution must be exercised to ensure that both sheets start melting at the same time. Heat is not distributed uniformly in the lap joint, **Figure 32-34**. Because of this difference in heating rate, the flame must be directed on the bottom sheet and away from the metal top sheet, **Figure 32-35**. The filler rod should be added to the top sheet. Gravity will pull the molten weld pool down to the bottom sheet; therefore, it is not necessary to put metal on the bottom sheet. If the filler metal is not added to the top sheet or if it is not added fast enough, surface tension will pull the molten weld pool back from the joint, **Figure 32-36**. When this happens, the rod should be added directly into this notch, and it will close. The weld appearance and strength will not be affected.

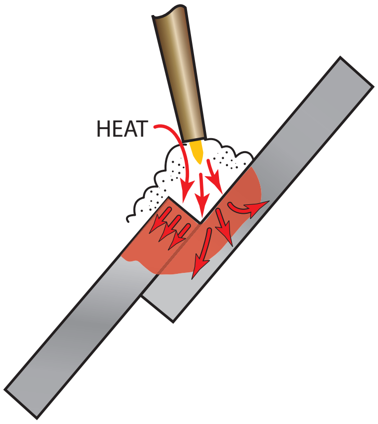


FIGURE 32-34 Heat is conducted away faster in the bottom plate, resulting in the top plate melting more quickly.

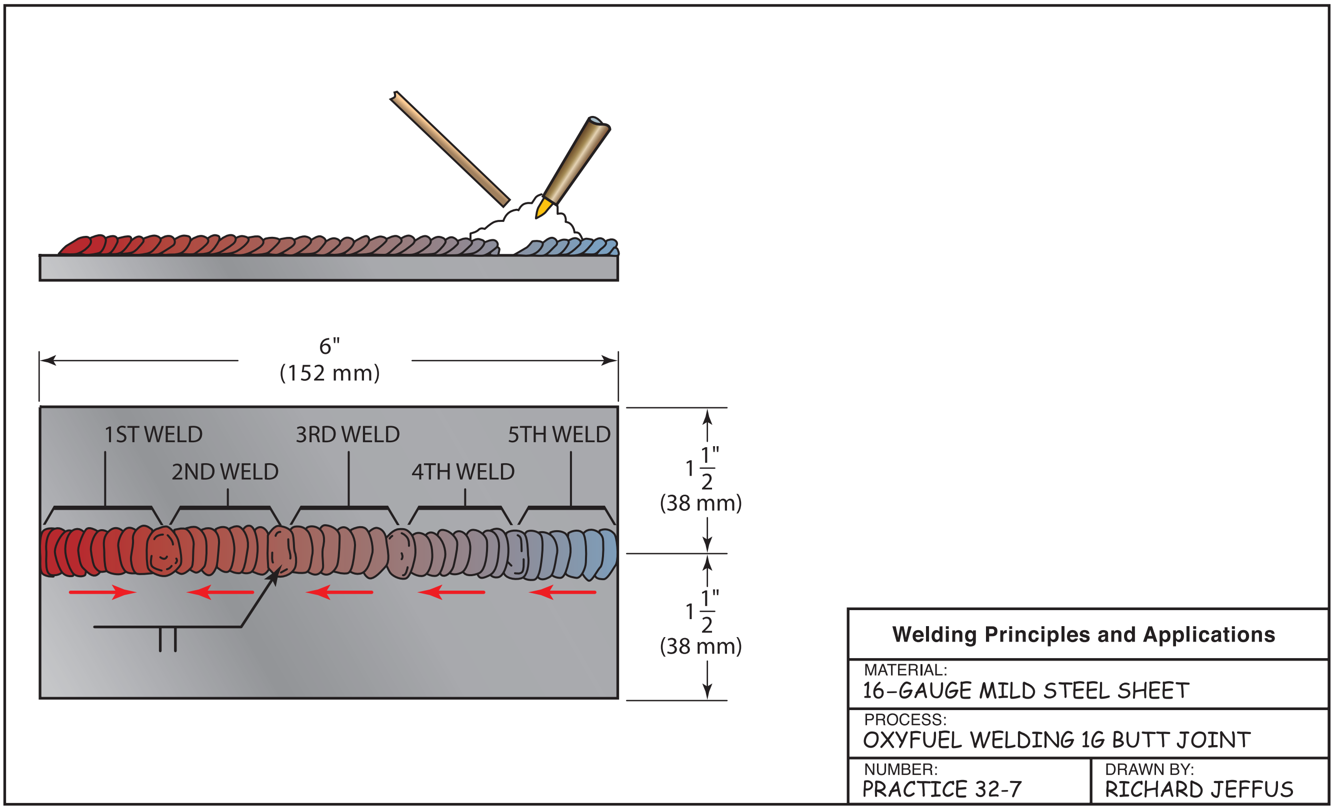


FIGURE 32-33 Welding with minimum distortion.

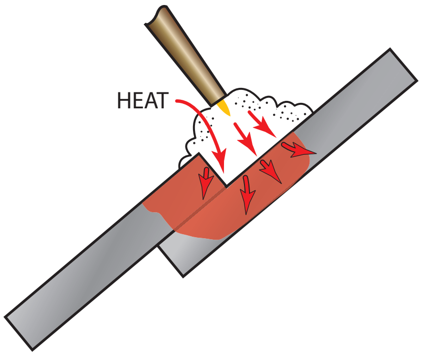


FIGURE 32-35 Flame heat should be directed at the bottom plate to compensate for thermal conductivity.

PRACTICE 32-8

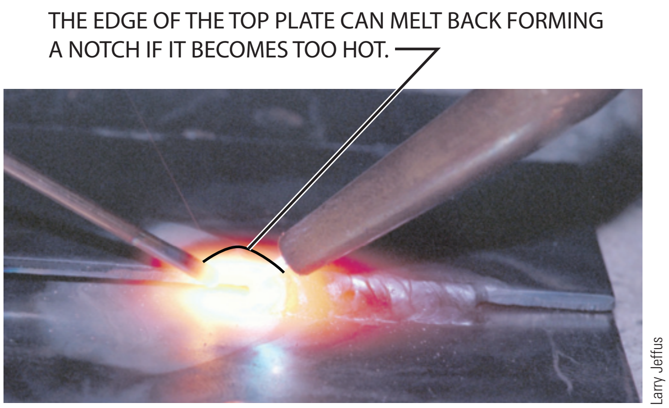
Lap Joint, Flat Position

Using a properly lit and adjusted torch, two clean pieces of 16-gauge mild steel 6 in. (152 mm) long, and filler metal, you will make a welded lap joint, **Figure 32-37**. Place the two pieces of metal on a firebrick and tack both ends, as shown in **Figure 32-38** and **Figure 32-39**. Make two or three more tack welds. Starting at one end, make a uniform weld along the joint. Both sides of the joint can be welded. Repeat this practice until the weld can be made without defects. If you want to test your skill, shear out a strip 1 in. (25 mm) wide, as shown in **Figure 32-40**, and test it for 100% root penetration, **Figure 32-41**. Turn off the cylinders, bleed the hoses, back out the regulator adjusting screws, and clean your work area when you are finished.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

Tee Joint

The flat **tee joint** is more difficult to make than the butt or lap joint. The tee joint has the same problem with uneven heating that the lap joint does. It is important to



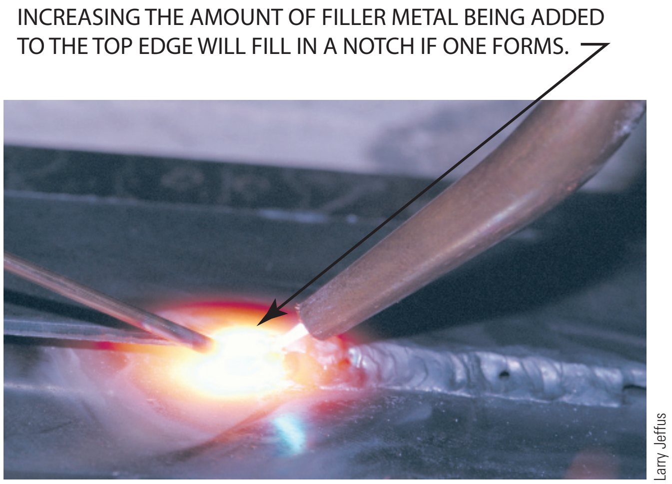


FIGURE 32-36 Adding filler metal to a lap joint weld.

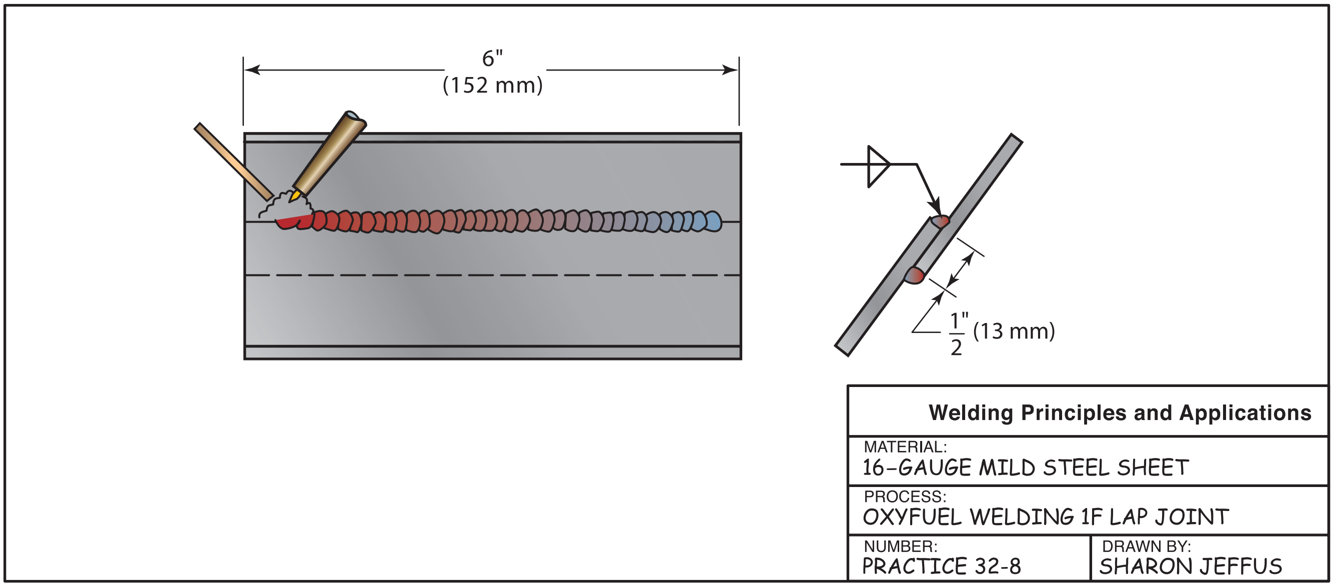


FIGURE 32-37 Lap joint.

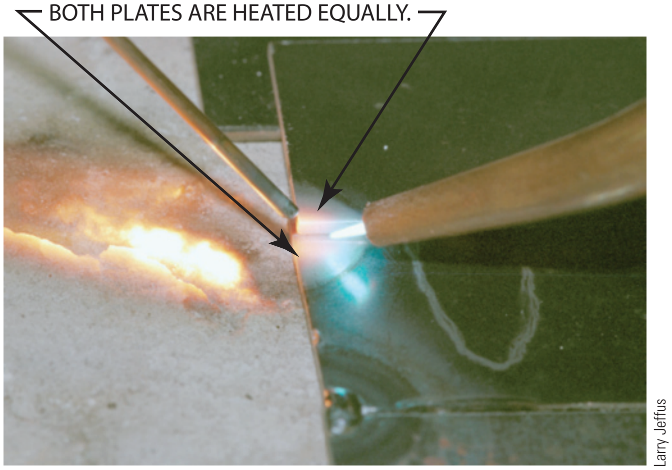


FIGURE 32-38 Heating the joint before tacking.

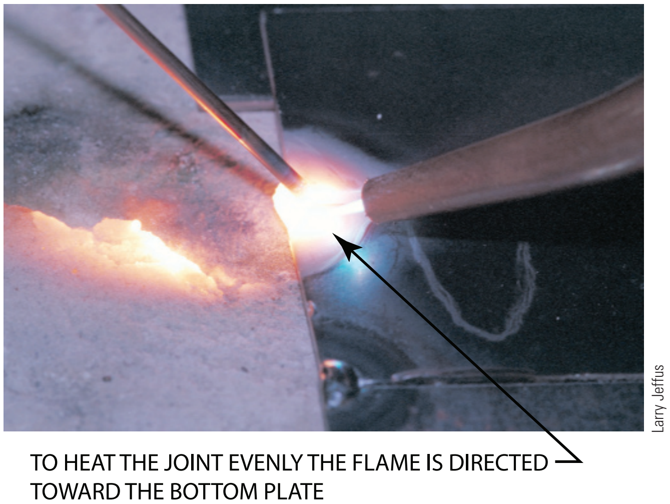


FIGURE 32-39 Filler rod is added after both pieces are heated to a melt.

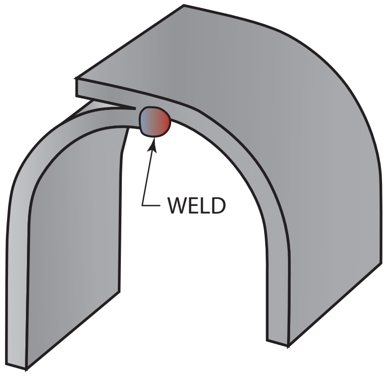


FIGURE 32-41 The 180° bend to test lap weld quality.

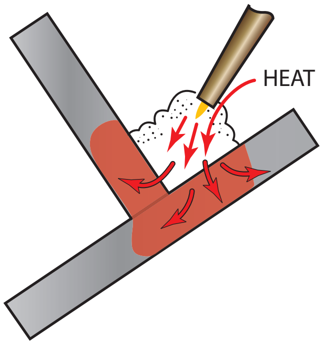


FIGURE 32-42 Direct the heat on the bottom plate to equalize the heating rates.

hold the flame so that both sheets melt at the same time, **Figure 32-42**. Another problem that is unique to the tee joint is that a large percentage of the welding heat is reflected back on the torch. This reflected heat can cause even a properly cleaned and adjusted torch to backfire

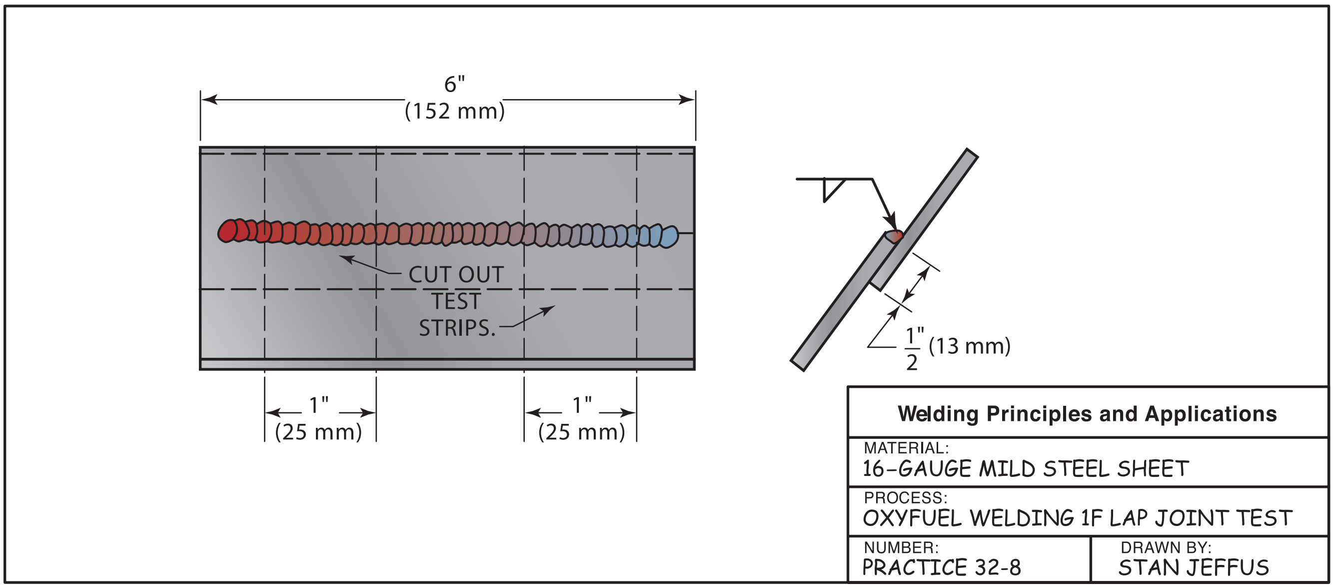


FIGURE 32-40 Cut-out test strips.

or pop. To help prevent this from happening, angle the torch more in the direction of the weld travel. Because of the slightly restricted atmosphere of the tee joint, it may be necessary to adjust the flame so that it is somewhat oxidizing. The beginning student should not be overly concerned with this.

PRACTICE 32-9

Tee Joint, Flat Position

Using a properly lit and adjusted torch, two clean pieces of 16-gauge mild steel 6 in. (152 mm) long, and filler metal, you will weld a flat tee joint, **Figure 32-43**.

Place the first piece of metal flat on a firebrick and hold or brace the second piece vertically on the first piece. The vertical piece should be within 5° of square to the bottom sheet. Tack the two sheets at the ends. Then, put two or three more tacks along the joint and brace the tee joint in position. If you want to test your skill, cut out a strip 1 in. (25 mm) wide, as shown in **Figure 32-44**, and test it for 100% root penetration, **Figure 32-45**. Turn off the cylinders, bleed the hoses, back out the regulator adjusting screws, and clean your work area when you are finished.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

OUT-OF-POSITION WELDING

A part to be welded cannot always be positioned so that it can be welded in the flat position. Whenever a weld is performed in a position other than flat, it is said to be **out-of-position welding**. Welds made in the vertical, horizontal, or overhead position are out of position and somewhat more difficult than flat welds.

VERTICAL WELDS

A **vertical weld** is the most common out-of-position weld that a welder is required to perform. When making a vertical weld, it is important to control the size of the molten weld pool. If the molten weld pool size increases beyond that which the **shelf** will support, **Figure 32-46**, the molten weld pool will overflow and drip down the weld. These drops, when cooled, look like the drips of wax on a candle. To prevent the molten weld pool from dripping, the trailing edge of the molten weld pool must be watched. The **trailing edge** will constantly be solidifying, forming a new shelf to support the molten weld pool as the weld progresses

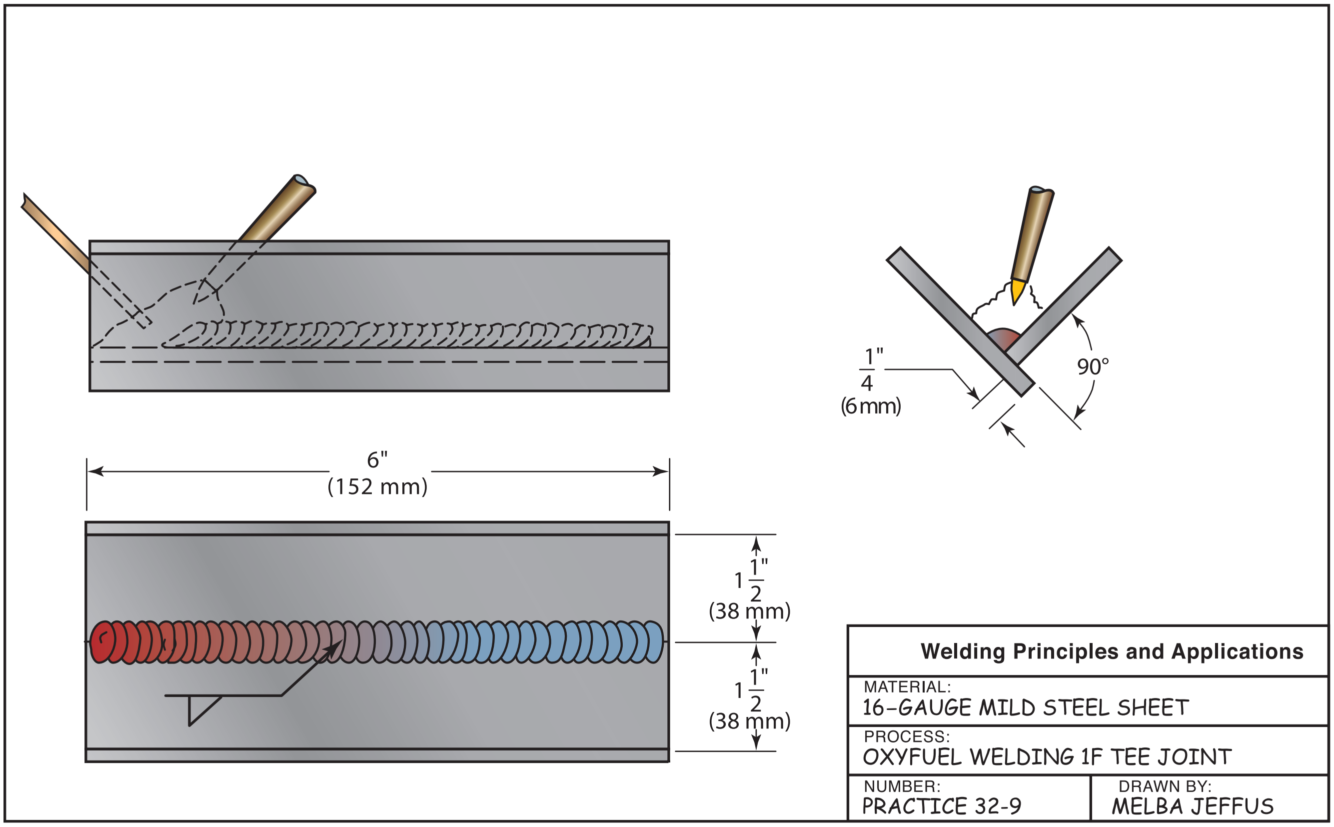


FIGURE 32-43 Tee joint.

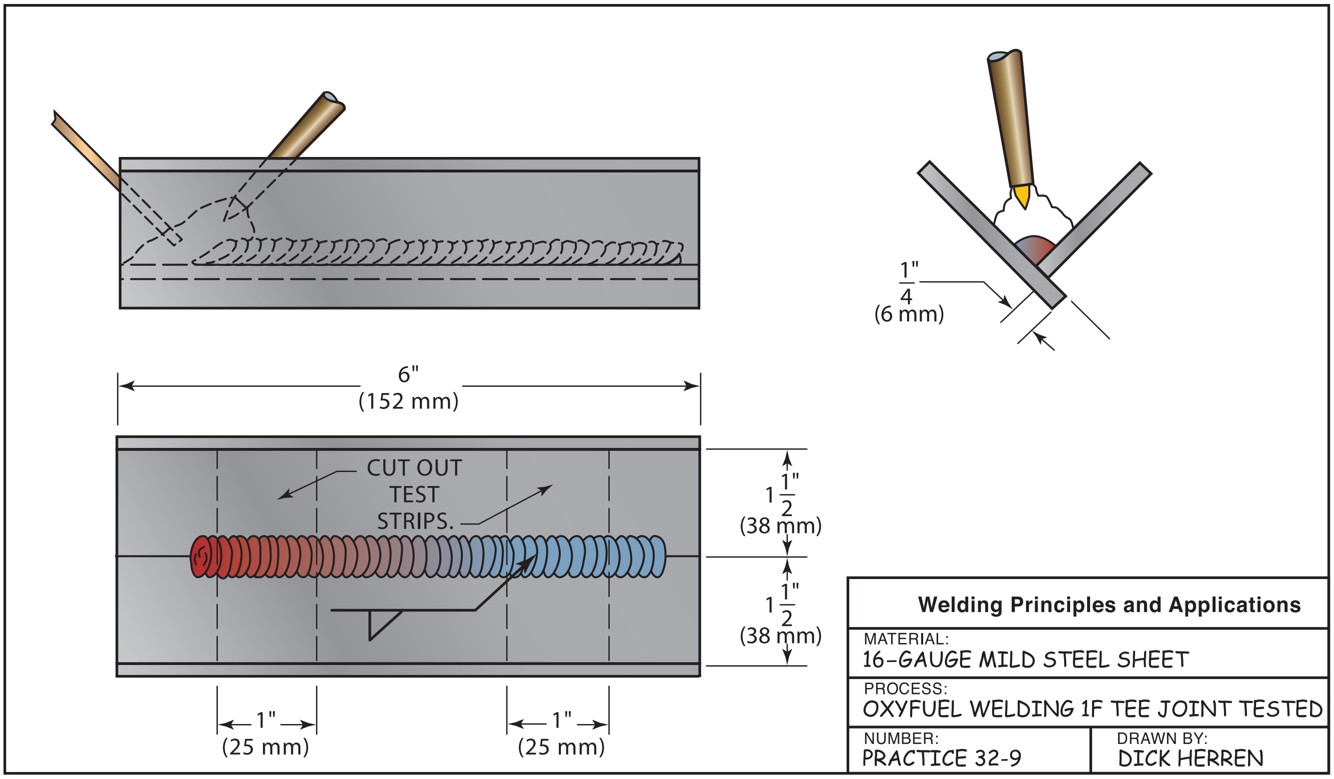


FIGURE 32-44 Cutout strips for testing.

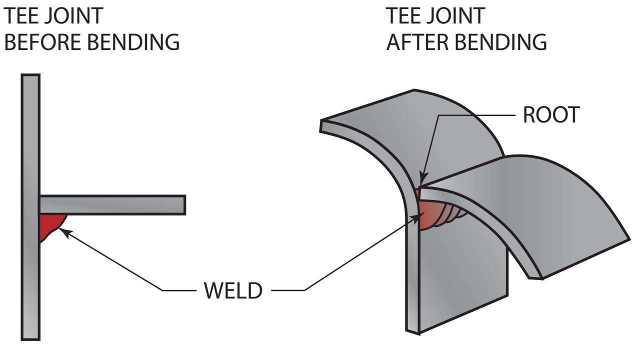


FIGURE 32-45 Bend the test strip to be sure the weld has good root fusion.

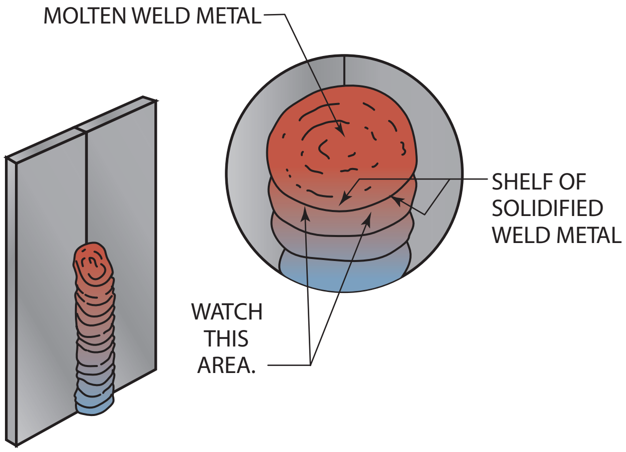


FIGURE 32-47 Watch the trailing edge to see that the molten pool stays properly supported on the shelf.

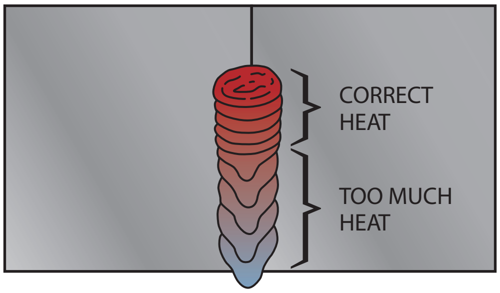


FIGURE 32-46 Vertical weld showing effect of too much heat.

upward, **Figure 32-47**. Small molten weld pools are less likely than large ones to drip.

The less vertical the sheet, the easier the weld is to make, but the type of manipulation required is the same. Welding on a sheet at a 45° angle requires the same manipulation and skill as welding on a vertical sheet. However, the speed of manipulation is slower, and the skill is less critical than at 90° vertical. This welding technique should be mastered at a 45° angle. Then, the angle of the

sheet is increased until it is possible to make totally vertical welds. Each practice weld in this section should be started on an incline and, as skill is gained, the angle should be increased until the sheets are vertical.

PRACTICE 32-10

Stringer Bead at a 45° Angle

Using a properly lit and adjusted torch, two clean pieces of 16-gauge mild steel 6 in. (152 mm) long, and filler metal, you will make a bead at a 45° angle.

The filler metal should be added as you did in Practice 32-3. It may be necessary to flash the torch off the molten weld pool to allow it to cool. **Flashing** the torch off allows the molten weld pool to cool by moving the hotter inner cone away from the molten weld pool itself. While still protecting the molten metal with the outer flame envelope, a rhythm of moving the torch and adding the rod should be established. This rhythm helps make the bead uniform. Repeat this practice until the weld can be made without defects. Turn off the cylinders, bleed the hoses, back out the regulator adjusting screws, and clean your work area when you are finished.

NOTE

By carefully controlling the torch's flame a weld can actually be made vertically, **Figure 32-48A**, **B**, and **C**. With practice by controlling the heat, the weld can be made horizontally above the plate surface, **Figure 32-48D**. Being able to control the weld bead this accurately can be very helpful for out-of-position welds and for filling gaps and holes for repair welding.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 32-11

Stringer Bead, Vertical Position

Repeat Practice 32-10 until you have mastered a straight and uniform weld bead in a vertical position. Turn off the

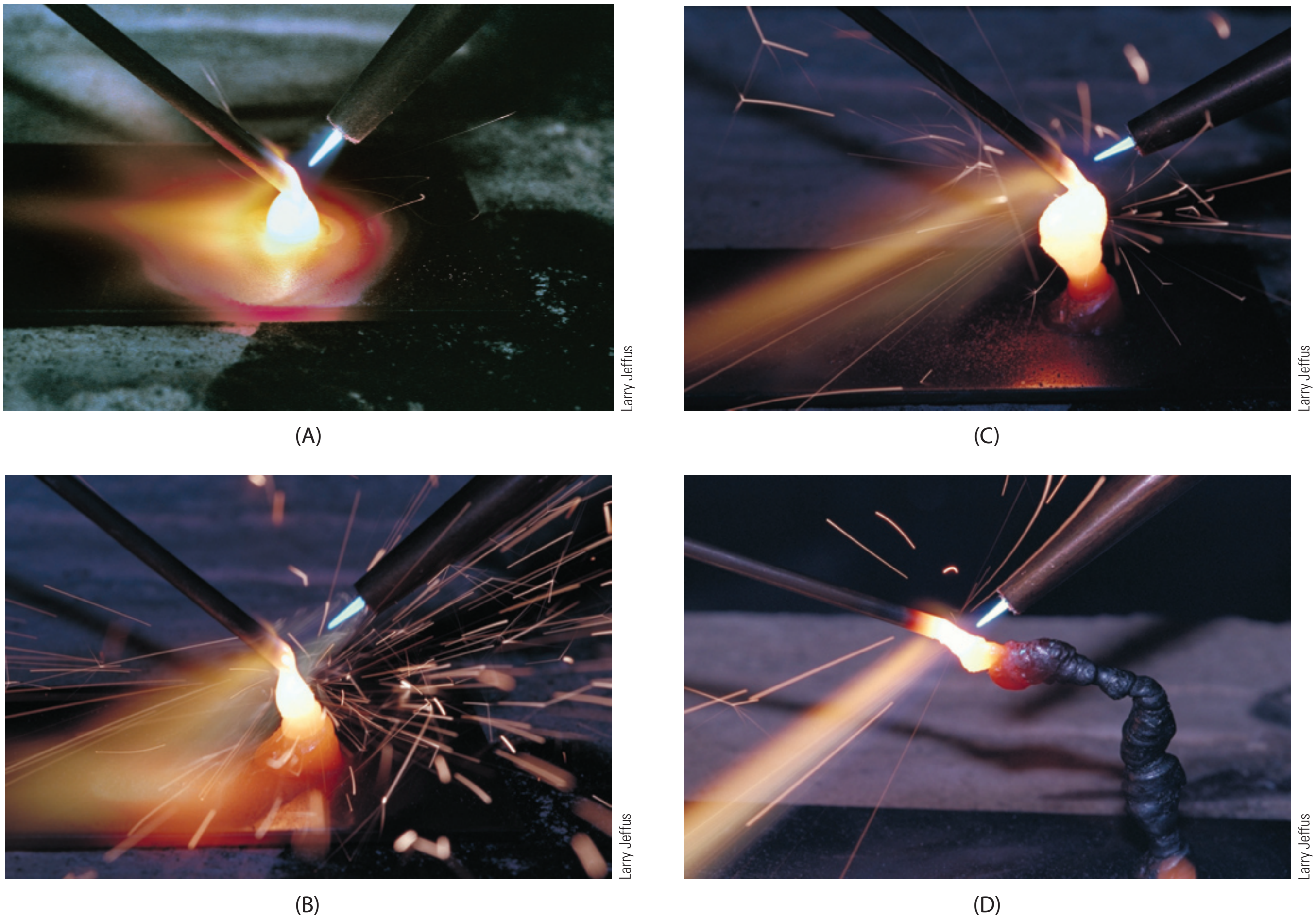


FIGURE 32-48 By flashing the flame off and controlling the pool size, a weld can be built up (A), and up (B), and over (C), and over (D).

cylinders, bleed the hoses, back out the regulator adjusting screws, and clean your work area when you are finished.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

Butt Joint

PRACTICE 32-12

Butt Joint at a 45° Angle

Using a properly lit and adjusted torch, two clean pieces of 16-gauge mild steel 6 in. (152 mm) long, and filler metal, you will make a welded butt joint at a 45° angle, **Figure 32-49**.

Tack the sheets together and support them at a 45° angle. Weld using the method of flashing the torch off the molten weld pool to control penetration and weld contour. Make a weld that has uniform width and reinforcement. Repeat this practice until the weld can be made without defects. Turn off the cylinders, bleed the hoses, back out the regulator adjusting screws, and clean your work area when you are finished.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 32-13

Butt Joint, Vertical Position

Using the same equipment, materials, and setup as described in Practice 32-12, make a welded butt joint in the vertical position. Make a weld that is uniform in width and buildup and has no visual defects. The penetration of this practice weld may vary. Turn off the cylinders, bleed the hoses, back out the regulator adjusting screws, and clean your work area when you are finished.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 32-14

Butt Joint, Vertical Position, with 100% Penetration

Using the same equipment, materials, and setup as listed in Practice 32-12, weld a butt joint in the vertical position with 100% penetration along the entire 6 in. (152 mm) of the welded joint. Repeat this practice until this weld can be made without defects. If you want to test your skill, shear out a strip 1 in. (25 mm) wide and test it for 100% root penetration, **Figure 32-50**. Turn off the cylinders, bleed the

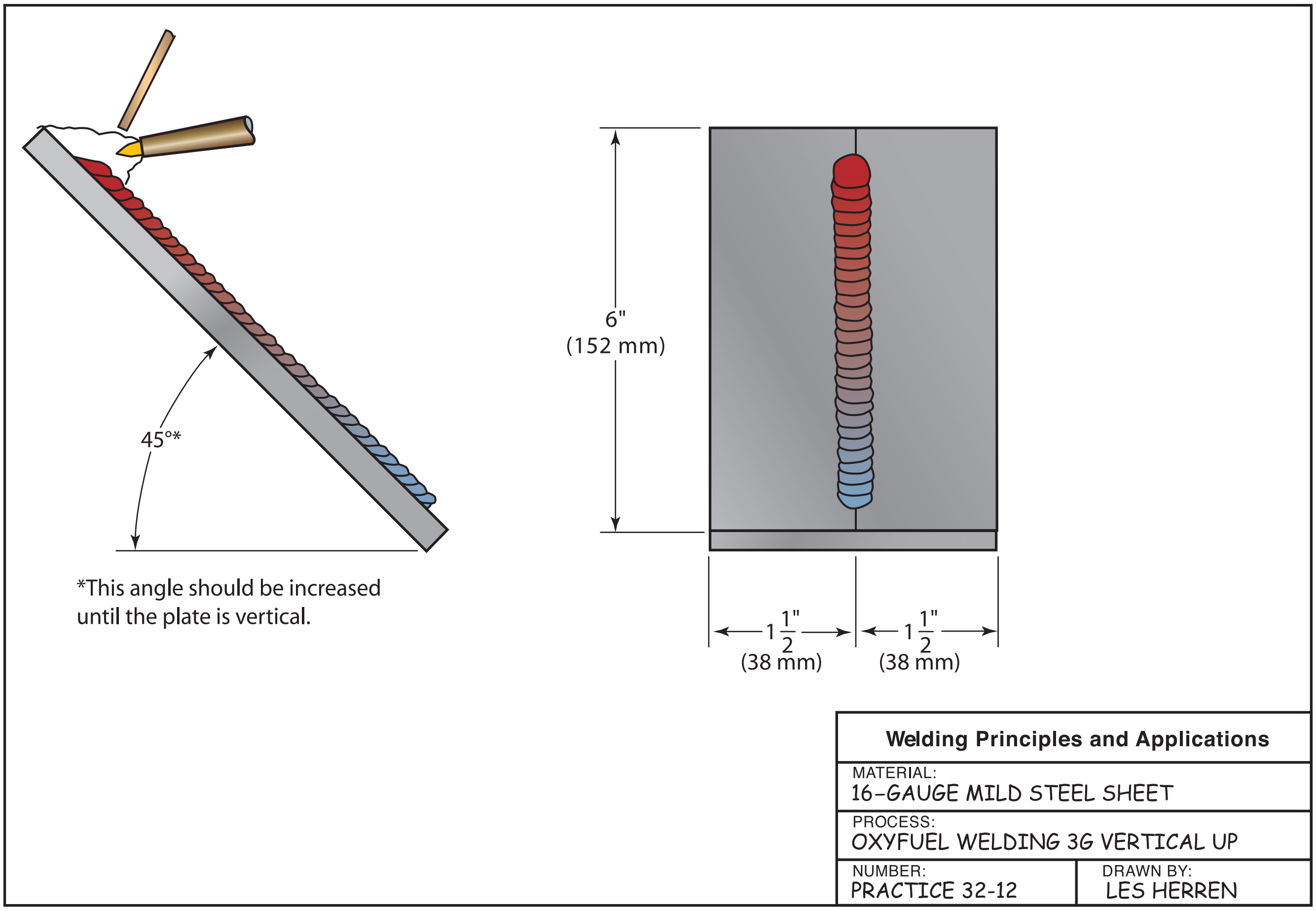


FIGURE 32-49 Butt joint at a 45° angle.

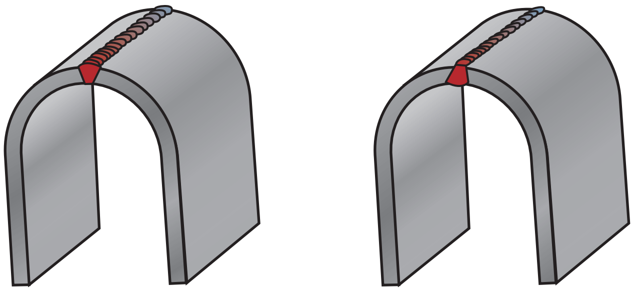


FIGURE 32-50 Bend strips to check a weld.

hoses, back out the regulator adjusting screws, and clean your work area when you are finished.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

Lap Joint

PRACTICE 32-15

Lap Joint at a 45° Angle

Using a properly lit and adjusted torch, two clean pieces of 16-gauge mild steel 6 in. (152 mm) long, and filler metal, you will weld a lap joint at a 45° angle.

After tacking the sheets together and supporting them at a 45° angle, use the same method of adding rod as you did for the flat lap joint. Again, flash off the torch as needed to control the molten weld pool.

Repeat this weld until you can make a weld that is uniform in width and reinforcement and has no visual defects. Both sides of the joint can be welded. Turn off the cylinders, bleed the hoses, back out the regulator adjusting screws, and clean your work area when you are finished.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 32-16

Lap Joint, Vertical Position

Using the same equipment, materials, and setup as listed in Practice 32-15, weld a lap joint in the vertical position. Make a weld that is uniform in width and reinforcement and has no visual defects. Both sides of the joint can be welded. Repeat this practice until the weld can be made without defects. If you want to test your skill, shear out a strip 1 in. (25 mm) wide and test it for 100% root penetration. Turn off the cylinders, bleed the hoses, back out the regulator adjusting screws, and clean your work area when you are finished.

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Tee Joint

The vertical tee joint has a right side and a left side. **Figure 32-51** shows the best way to place the sheets depending on whether the welder is right-handed or left-handed. It is a good idea to try both the right-hand and left-hand joints because in the field you may not be able to change the joint direction. Use the same method of adjusting the torch and torch angle that was practiced for the flat tee joint. In addition, use the method of flashing off the torch for molten weld pool control. Surface tension in the molten weld pool of a tee joint enables a larger weld to be

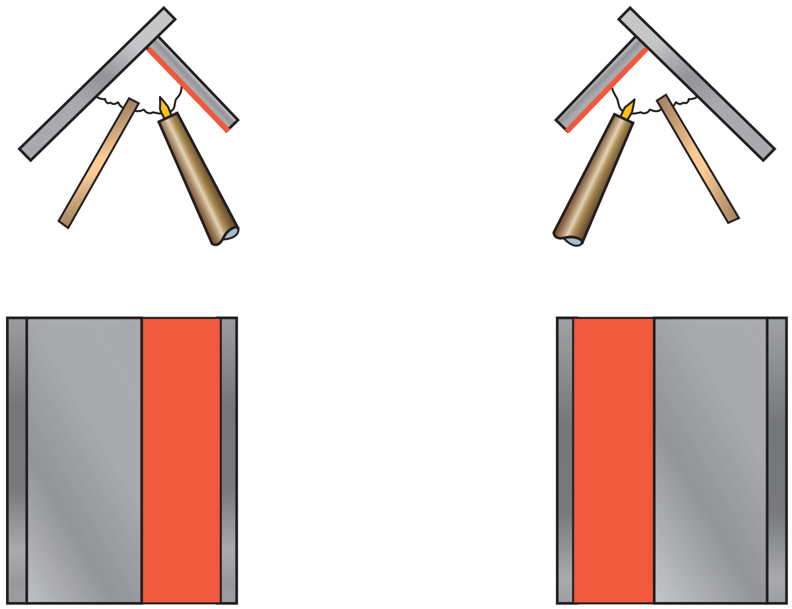

FIGURE 32-51 Some vertical tee joints are easier for right-handed or left-handed welders.

made than either the butt joint or the lap joint without as severe of a problem with dripping.

PRACTICE 32-17

Tee Joint at a 45° Angle

Using a properly lit and adjusted torch, two clean pieces of 16-gauge mild steel 6 in. (152 mm) long, and filler metal, you will weld a tee joint at a 45° angle.

After tacking the sheets together and supporting them at a 45° angle, make a fillet weld that has uniform width and reinforcement and no visual defects. It is often best to weld only one side of the practice tee joint unless the oxides can be easily removed from the back side of the previous weld. Repeat this practice until the weld can be made without defects. Turn off the cylinders, bleed the hoses, back out the regulator adjusting screws, and clean your work area when you are finished.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 32-18

Tee Joint, Vertical Position

Using the same equipment, materials, and setup as listed in Practice 32-17, make a fillet weld. Cut out a strip 1 in. (25 mm) wide (refer to Figure 32-44) and test it for 100% root penetration. Repeat this practice until the weld passes the test. Turn off the cylinders, bleed the hoses, back out the regulator adjusting screws, and clean your work area when you are finished.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

HORIZONTAL WELDS

Horizontal welds, like vertical welds, must rely on some part of the weld bead to support the molten weld pool as the weld is made. The shelf that supports a horizontal weld must be built up under the molten weld pool and at the same time must keep the weld bead uniform. The weave pattern required for a horizontal weld is completely different from that of any of the other positions. The pattern, **Figure 32-52**, builds a shelf on the bottom side of the bead to support the molten weld pool, which is elongated across the top. The sheet may be tipped back at a 45° angle for the stringer bead. Doing this allows the student to acquire the needed skills before proceeding to the more difficult, fully horizontal position. As with the vertically inclined sheet, the skills required are the same.

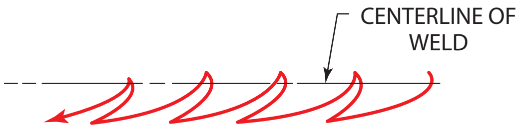

FIGURE 32-52 A "J" weave pattern for horizontal welds.

Horizontal Stringer Bead

When starting a horizontal bead, it is important to start with a small bead and build it to the desired size. If too large of a molten weld pool is started, the shelf does not have time to form properly. The weld bead will tend to sag downward and not be uniform. As a result, there may be an **undercut** of the top edge and an **overlap** on the bottom edge, **Figure 32-53**.

PRACTICE 32-19

Horizontal Stringer Bead at a 45° Angle

Using a properly lit and adjusted torch, one clean piece of 16-gauge mild steel 6 in. (152 mm) long, and filler metal, you will make a horizontal bead at a 45° reclining angle, **Figure 32-54**.

Add the filler metal along the top leading edge of the molten weld pool. Surface tension will help hold it on the top. The weld should be uniform in width and reinforcement and have no visual defects. Repeat this practice until the weld can be made without defects. Turn off the cylinders, bleed the hoses, back out the regulator adjusting screws, and clean your work area when you are finished.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 32-20

Stringer Bead, Horizontal Position

Using the same equipment, materials, and setup as listed in Practice 32-19, make a stringer bead in the horizontal position. The stringer bead should be uniform in width

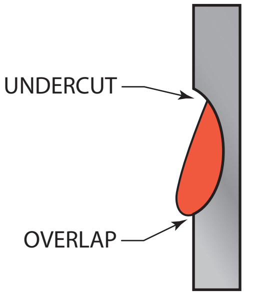

FIGURE 32-53 Too large of a molten weld pool.

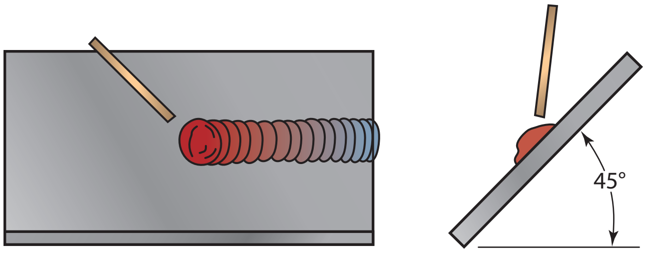

FIGURE 32-54 Horizontal stringer bead at a reclining angle.

and reinforcement and have no visual defects. Turn off the cylinders, bleed the hoses, back out the regulator adjusting screws, and clean your work area when you are finished.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

Butt Joint

PRACTICE 32-21

Butt Joint, Horizontal Position

Using a properly lit and adjusted torch, two clean pieces of 16-gauge mild steel 6 in. (152 mm) long, and filler metal, you will weld a butt joint in the horizontal position.

After tacking the sheets together and supporting them in the horizontal position, make a weld using the same technique as practiced in the horizontal beading, Practice 32-20. The weld must be uniform in width and buildup and have no visual defects. If you want to test your skill, shear out a strip 1 in. (25 mm) wide and test it for 100% root penetration. Repeat this practice until the weld can be made without defects. Turn off the cylinders, bleed the hoses, back out the regulator adjusting screws, and clean your work area when you are finished.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

Lap Joint

PRACTICE 32-22

Lap Joint, Horizontal Position

Using a properly lit and adjusted torch, two clean pieces of 16-gauge mild steel 6 in. (152 mm) long, and filler metal, you will weld a lap joint in the horizontal position.

After tacking the sheets together, support the assembly as illustrated in **Figure 32-55**. The weld must be uniform in width and buildup and have no visual defects. The sheet can be turned over, and the other side can be welded. If you want to test your skill, shear out a strip 1 in. (25 mm) wide and test it for 100% root penetration. Repeat this practice until the weld can be made without defects. Turn off the cylinders, bleed the hoses, back out the regulator adjusting screws, and clean your work area when you are finished.

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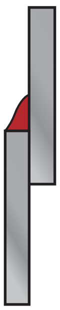

FIGURE 32-55 Horizontal lap joint.

Tee Joint

The horizontal and flat tee joints are very similar in relation to the types of skills required to perform metal welds. The horizontal fillet weld tends to flow down toward the horizontal sheet from the vertical sheet. To correct this problem, the filler metal should be added to the top edge of the molten weld pool.

PRACTICE 32-23

Tee Joint, Horizontal Position

Using a properly lit and adjusted torch, two clean pieces of 16-gauge mild steel 6 in. (162 mm) long, and filler metal, you will weld one side of a tee joint in the horizontal position. After tacking the sheets together, make a fillet weld that is uniform in width and reinforcement and has no visual defects. If you want to test your skill, shear out a strip 1 in. (25 mm) wide and test it for 100% root penetration. Repeat this practice until the weld can be made without defects. Turn off the cylinders, bleed the hoses, back out the regulator adjusting screws, and clean your work area when you are finished.

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OVERHEAD WELDS

When welding in the overhead position, it is important to wear the proper personal protection, including leather gloves, leather sleeves, a leather apron, and a cap. The possibility of being burned increases greatly when welding in the overhead position. However, with the proper protective clothing you should avoid being burned.

With the **overhead weld**, the molten weld pool is held to the sheet by surface tension in the same manner that a drop of water is held to the bottom of a glass sheet. If the molten weld pool gets too large, big drops of metal may fall. If the welding rod is not dipped into the molten weld pool, but is allowed to melt in the flame, it also may drip. As long as the molten weld pool is controlled and the rod is added properly, overhead welding is safe.

The direction that you choose to weld in the overhead position is one of personal preference. It is a good idea to try several directions before deciding on one. The height of the sheet also affects your skill and progress. Welders often prefer to stand while overhead welding so that sparks do not land in their laps. If you decide to stand, you need to somehow brace yourself to help your stability.

Stringer Bead

Place the metal at a height recommended by your instructor. With the torch off, your goggles down, and a rod in your hand, try to progress across the sheet in a straight line. Use several directions until you find the direction that best suits you. Change the height of the sheet up and down to determine the height at which welding is most comfortable.

PRACTICE 32-24

Stringer Bead, Overhead Position

Using a properly lit and adjusted torch and one clean piece of 16-gauge mild steel 6 in. (152 mm) long, you will make a bead in the overhead position.

Heat the sheet until it melts and forms a molten weld pool. Put the welding rod into the molten weld pool as the torch tip is moved away from the molten weld pool. Return the flame to the molten weld pool as you remove the rod, **Figure 32-56**. Continue repeating this sequence as you move along the sheet. The weld bead should be uniform in width and buildup and have no visual defects. Repeat this practice until the weld can be made without defects. Turn off the cylinders, bleed the hoses, back out the regulator adjusting screws, and clean your work area when you are finished.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

Butt Joint

PRACTICE 32-25

Butt Joint, Overhead Position

Using a properly lit and adjusted torch, two clean pieces of 16-gauge mild steel 6 in. (152 mm) long, and filler metal, you will weld a butt joint in the overhead position.

After tacking the sheets together, put them in the overhead position. Following the sequence used in Practice 32-24 for the overhead stringer bead, make a weld along the joint. The weld should be uniform in width and reinforcement and have no visual defects. If you want to test your skill, shear out a strip 1 in. (25 mm) wide and test it for 100% root penetration. Repeat this practice until the weld can be made without defects. Turn off the cylinders, bleed the hoses, back out the regulator adjusting screws, and clean your work area when you are finished.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

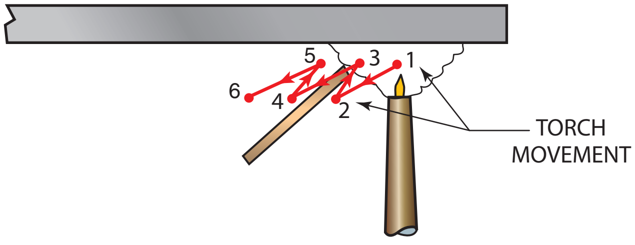

FIGURE 32-56 Overhead.

Lap Joint

PRACTICE 32-26

Lap Joint, Overhead Position

Using a properly lit and adjusted torch, two clean pieces of 16-gauge mild steel 6 in. (152 mm) long, and filler metal, you will weld a lap joint in the overhead position.

After tacking the sheets together, put them in the overhead position. Using the sequence for the overhead stringer bead, make a weld down the joint. The filler metal should be added to the leading edge of the molten weld pool on the top sheet. The weld should be uniform in width and buildup and have no visual defects. If you want to test your skill, shear out a strip 1 in. (25 mm) wide and test it for 100% root penetration. Repeat this practice until the weld can be made without defects. Turn off the cylinders, bleed the hoses, back out the regulator adjusting screws, and clean your work area when you are finished.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

Tee Joint

PRACTICE 32-27

Tee Joint, Overhead Position

Using a properly lit and adjusted torch, two clean pieces of 16-gauge mild steel 6 in. (152 mm) long, and filler metal, you will weld one side of a tee joint in the overhead position.

After tacking the sheets together, put them in the overhead position and make a fillet weld. The filler metal should be added to the top sheet. The weld should be uniform in width and buildup and have no visual defects. If you want to test your skill, cut out a strip 1 in. (25 mm) wide and test it for 100% root penetration. Repeat this practice until the weld can be made without defects. Turn off the cylinders, bleed the hoses, back out the regulator adjusting screws, and clean your work area when you are finished.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

MILD STEEL PIPE AND TUBING

Mild steel pipe and tubing, both small diameter and thin wall, can be gas welded. The welding process for both pipe and tubing is usually the same. Thin-wall material does not require a grooved preparation. Gas welding is very seldom used to manufacture piping systems. It is used on both pipe and tubing to make structures, such as bicycle and

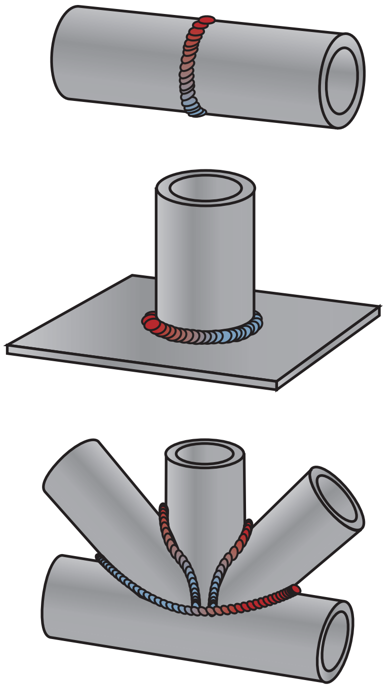

FIGURE 32-57 Examples of tube joints commonly used in industry.

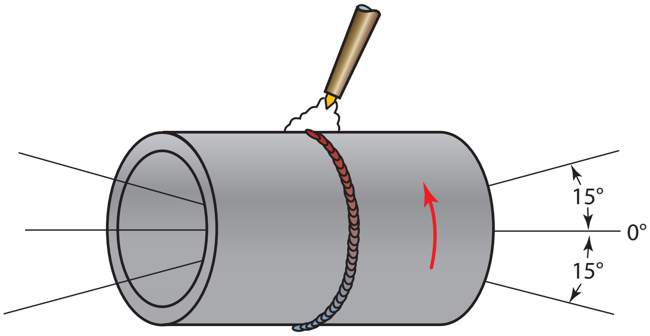

FIGURE 32-58 1G position. The pipe is rolled horizontally. The weld is made in the flat position (approximately 12 o'clock as the pipe is rolled).

motorcycle frames, gates, works of art, handrails, and light aircraft frames, **Figure 32-57.**

HORIZONTAL ROLLED POSITION 1G

The experiments and practices that follow (through Practice 32-29) will give the student the opportunity to gain skill in making welds in the **1G position**, **Figure 32-58**.

EXPERIMENT 32-4

Effect of Changing Angle on Molten Weld Pool

This experiment will show how the molten weld pool is affected by changing the surface angle. Using a piece of pipe with a diameter of approximately 2 in. (51 mm), you

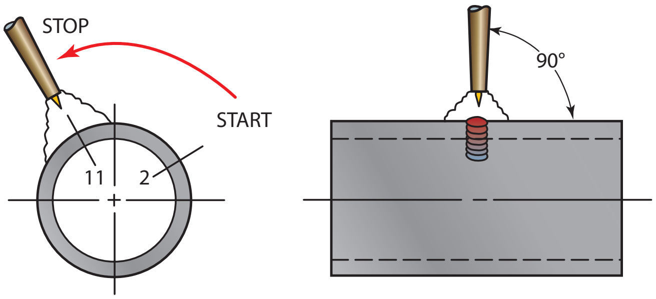

FIGURE 32-59 When the weld is finished, stop and roll the pipe so that the end of the weld is at the 2 o'clock position.

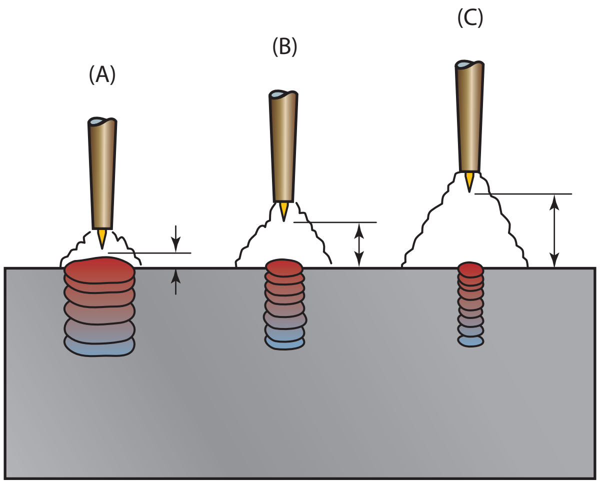

FIGURE 32-60 As the distance between the inner core and pipe changes, the size of the molten weld pool changes.

will push a molten weld pool across the top of the pipe. The pipe is in the 1G position, **Figure 32-59**. Starting at the 2 o'clock position, weld upward and across to the 11 o'clock position. Use the same torch angle and distances that you learned in Practice 32-2 and Experiment 32-3. Repeat this experiment until you can make a straight weld bead that is uniform in width.

Keeping the torch at the correct angle to the pipe surface requires some practice. Changes in the relative torch angle will greatly affect the size of the molten weld pool. The distance of the inner core from the pipe surface is also important, **Figure 32-60**. You must be comfortable and able to freely move around. Your free hand should not be used for supporting or steadying the torch or yourself. Later, when you need this hand to add filler metal, you will not have to learn how to be steady without the use of your hand.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

EXPERIMENT 32-5

Stringer Bead, 1G Position

Using a properly lit and adjusted torch, one clean piece of pipe approximately 2 in. (51 mm) in diameter, and three

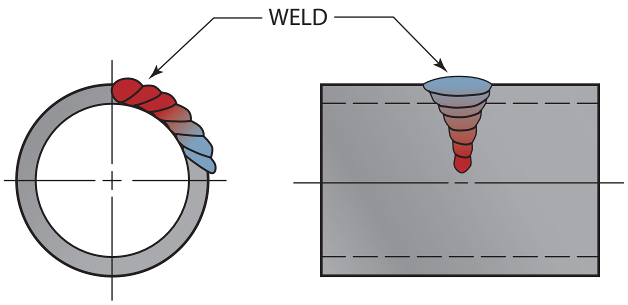

FIGURE 32-61 The weld bead shape is affected by its relative position on the pipe.

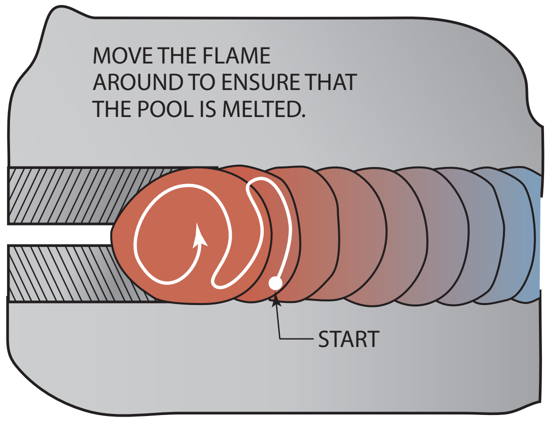

FIGURE 32-62 When restarting a weld pool, be sure the entire pool area is remelted before starting to add weld metal.

different sizes of filler metal, you will make a stringer bead on the pipe.

With the pipe in the 1G position, start a molten weld pool at the 2 o'clock position and weld to the 11 o'clock position. When you are at the 2 o'clock position, gravity will pull the molten metal outward, making the bead high and narrow, **Figure 32-61**. As the weld progresses toward the 12 o'clock position, if you keep using the same technique, the weld metal is pulled down, making the bead flat and wide. Repeat this experiment until you can make a straight weld bead that is uniform in width and reinforcement.

To keep the contour and width of the weld bead uniform, you must adjust your technique as the weld progresses. The following are some methods of keeping the buildup uniform:

- Move the flame farther from the surface of the pipe.
- Decrease the torch angle relative to the pipe surface.
- Travel at an increasing rate of speed.

A combination of these methods can be used to control the spreading weld bead. The spreading weld bead should be treated as if it is becoming too hot and you must cool it down. However, gravity rather than temperature is the problem, but decreasing the temperature can solve the problem.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

EXPERIMENT 32-6

Stops and Starts

Using a properly lit and adjusted torch, one clean piece of pipe with a diameter of approximately 2 in. (51 mm), and filler metal, you will learn how to make good starts and stops. When welding pipe, you will frequently need to stop and restart. With practice and the proper technique, it is possible to make uniform stops and starts that are as strong as the surrounding weld bead.

To make a proper stop, you should slightly taper down the molten weld pool by flashing the torch off. This allows the molten weld pool to solidify before the flame is totally removed from the weld pool. If the flame is removed too soon from the molten weld pool, it will rapidly oxidize, throwing out a burst of sparks. The pocket of oxides will greatly weaken the weld at this point.

Restarting the weld requires that a molten weld pool equal in size to the original one be established. To restart the molten weld pool, point the flame slightly ahead of the crater at the end of the weld bead, **Figure 32-62**. When this metal starts to melt, move the flame back to the weld crater and melt the entire crater. Once the crater melts, start adding filler metal and continue with the weld. If the metal ahead of the crater is not heated first when the weld metal is added to the crater, it may form a cold lap over the base metal.

Practice stops and starts until you can make them so that they are uniform and unnoticeable on the weld bead.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 32-28

Stringer Bead, 1G Position

Using a properly lit and adjusted torch and one clean piece of pipe approximately 2 in. (51 mm) in diameter, you will make a stringer bead around the pipe.

With the pipe in the 1G position, start a welding bead at the 2 o'clock position and weld toward the 12 o'clock position. When you must stop to change positions, roll the pipe so the ending crater is at the 2 o'clock position. Start the weld bead as practiced in Experiment 32-6 and proceed with the weld as before, **Figure 32-63**. Repeat this process until the weld bead extends all the way around the pipe. Repeat this practice until you can produce a straight weld bead that is uniform in width and reinforcement and has no visual defects. Turn off the cylinders, bleed the hoses, back out the regulator adjusting screws, and clean your work area when you are finished.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

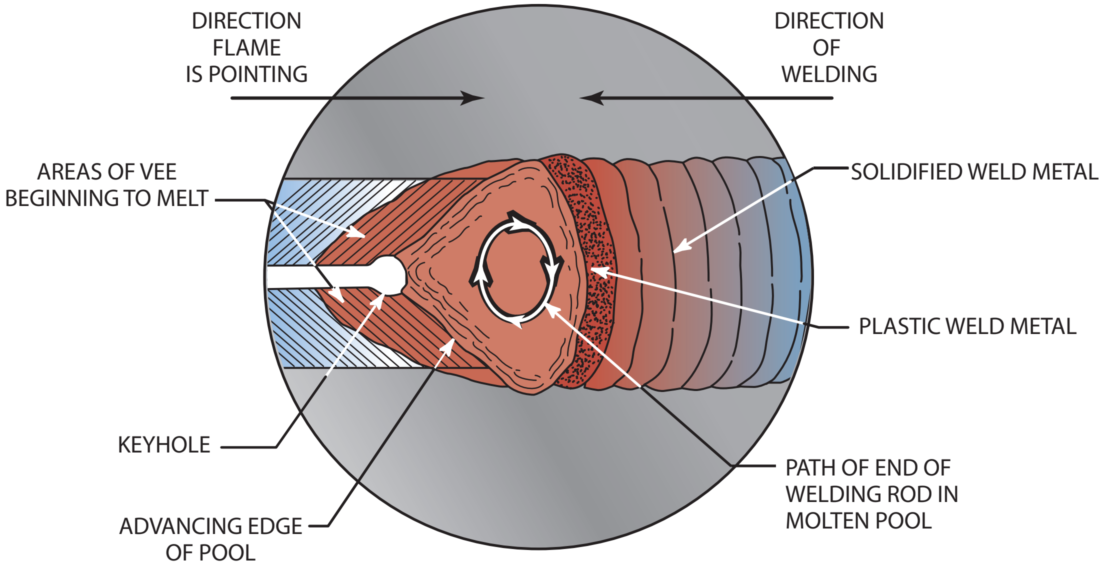

FIGURE 32-63 Pipe welding.

PRACTICE 32-29

Butt Joint, 1G Position

Using a properly lit and adjusted torch, two clean pieces of schedule 40 pipe approximately 2 in. (51 mm) in diameter, and filler metal, you will weld a butt joint in the 1G position.

The pipe ends should be prepared as shown in **Figure 32-64**. The weld will be made with one pass. Tack weld the pipe together and place it on a firebrick. Using the principles and applications you learned in Practice 32-28, make this weld. Repeat this weld until it can be made without defects. Turn off the cylinders, bleed the hoses, back out the regulator adjusting screws, and clean your work area when you are finished.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

HORIZONTAL FIXED POSITION 5G

The horizontal fixed position 5G weld, **Figure 32-65**, requires little skill development after completing the horizontal rolled position 1G welds. The torch height and angle skills you have developed will help you master the **5G position**.

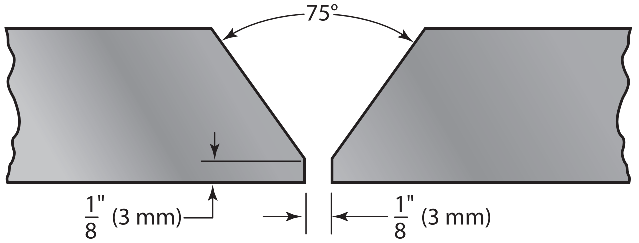

FIGURE 32-64 The bevel on the pipe may be oxyfuel flame cut, ground, or machined.

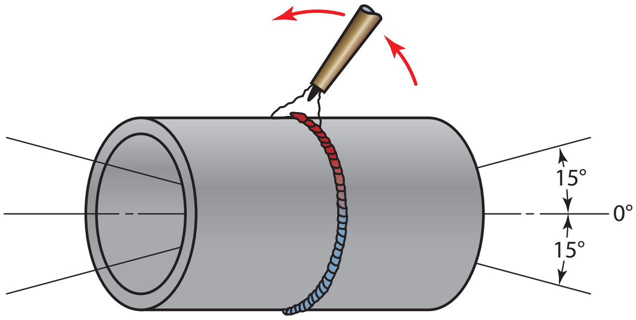

FIGURE 32-65 5G position. The pipe is fixed horizontally.

As the weld changes from overhead (6 o'clock) to vertical (3 o'clock), the weld contour changes. At the overhead position, the weld bead tends to be shaped as shown in **Figure 32-66**, **Section A-A**. Note that the bead is high in the center and recessed and possibly undercut on the sides. The vertical position has a high and narrow bead shape, **Figure 32-66**, **Section B-B**.

The overhead bead shape can be controlled by stepping the molten weld pool and moving the flame and rod back and forth at the same time. This process will deposit the metal and allow it to cool before it can sag. It allows the surface tension to hold the metal in place.

As the weld progresses toward the vertical section, the need to step the weld decreases. When the weld reaches the vertical section, the bead shape should be controlled by torch angle and flame distance.

EXPERIMENT 32-7

5G Position

In this experiment, you are going to push a molten weld pool from the bottom of a fixed pipe up to the side of the pipe to see how torch manipulation affects the bead shape.

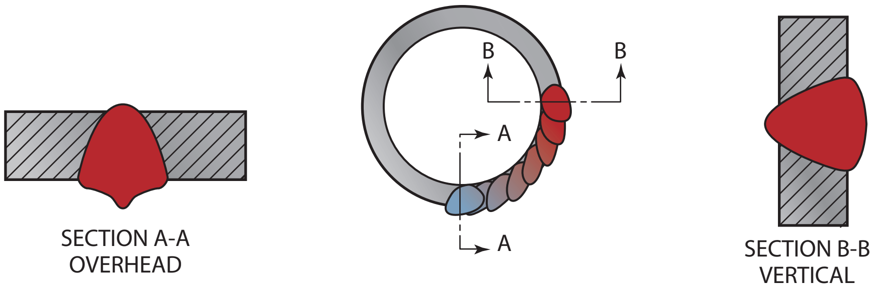

FIGURE 32-66 Changes in weld bead shape at different locations.

Using a properly lit and adjusted torch and one clean piece of pipe approximately 2 in. (51 mm) in diameter, start by establishing a molten weld pool at the 6 o'clock position. Then, move the molten weld pool forward toward the 3 o'clock position. Observe what effect torch angle, flame distance, and stepping have on the molten weld pool. Turn the pipe and repeat this experiment until you can control the bead width.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 32-30

Stringer Bead, 5G Position

Using a properly lit and adjusted torch, one clean piece of pipe with a diameter of approximately 2 in. (51 mm), and filler metal, you will make a stringer bead upward round one side of the pipe.

With the pipe in the 5G position, start a welding bead at the 6 o'clock position and weld toward the 12 o'clock position. Use all procedures necessary to keep the weld bead uniform. Repeat this practice until you can produce a straight weld bead that is uniform in width and reinforcement and has no visual defects. Turn off the cylinders, bleed the hoses, back out the regulator adjusting screws, and clean your work area when you are finished.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 32-31

Butt Joint, 5G Position

Using a properly lit and adjusted torch, two clean pieces of pipe with a diameter of approximately 2 in. (51 mm), and filler metal, you will weld a butt joint in the 5G position.

The pipe ends should be beveled as shown in Figure 32-64 and tack welded together. Secure the pipe on a stand, such as the one shown in **Figure 32-67**, and start welding at the 6 o'clock position, moving toward the 12 o'clock position. When you reach the top, stop, restart back at the 6 o'clock position, and continue up the other side. Repeat this weld until it can be made without defects. Turn off the cylinders, bleed the hoses, back out the regulator adjusting screws, and clean your work area when you are finished.

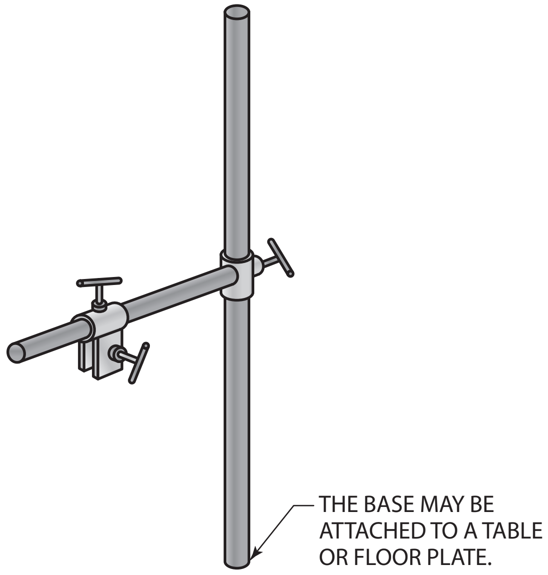

FIGURE 32-67 Pipe stand.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

VERTICAL FIXED POSITION 2G

The vertically fixed pipe requires a horizontal weld, **Figure 32-68**. The welding manipulative skill required for the **2G position** is similar to that for a horizontal butt joint. The pipe may be rotated around its vertical axis but may not be turned end for end after you have started welding, **Figure 32-69**.

PRACTICE 32-32

Stringer Bead, 2G Position

Using a properly lit and adjusted torch and one clean piece of pipe with a diameter of approximately 2 in. (51 mm), you will make a stringer bead around the pipe.

With the pipe in the 2G position, start with a small bead, as illustrated in **Figure 32-70**, and then increase the bead to the desired size. Starting small will allow you to build a shelf to support the molten weld pool. It also will let you tie the end of the weld into the start of the weld so that a stronger weld is obtained. Repeat this weld until it can

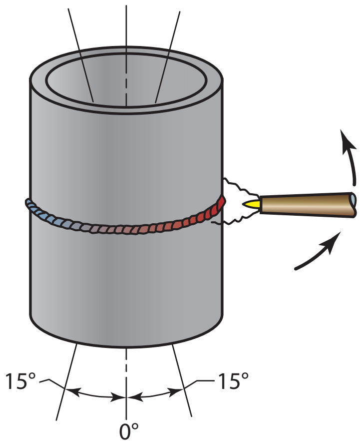

FIGURE 32-68 2G position. The pipe is fixed vertically and welded horizontally.

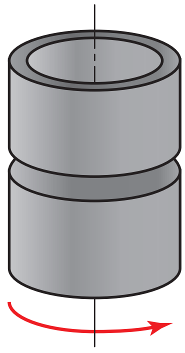

FIGURE 32-69 2G vertical fixed position.

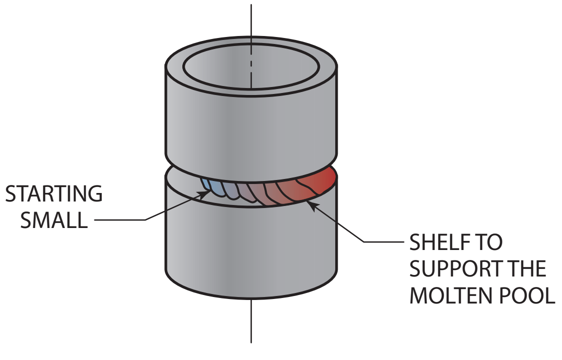

FIGURE 32-70 The proper starting technique will aid with tying in the weld when it is completed around the pipe.

be made without defects. Turn off the cylinders, bleed the hoses, back out the regulator adjusting screws, and clean your work area when you are finished.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 32-33

Butt Joint, 2G Position

Using a properly lit and adjusted torch, two clean pieces of pipe with a diameter of approximately 2 in. (51 mm), and filler metal, you will weld a butt joint in the 2G position. The pipe ends should be beveled and tack welded together. Secure the pipe in the vertical position and start welding. Repeat this weld until it can be made without defects. Turn off the cylinders, bleed the hoses, back out the regulator adjusting screws, and clean your work area when you are finished.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

45° FIXED POSITION 6G

The 45° fixed pipe position, **Figure 32-71**, requires careful manipulation of the molten weld pool to ensure a uniform and satisfactory weld. The weld progresses around the pipe, changing from vertical to horizontal to overhead to flat and not completely in any one position. It is the combination of compound angles that makes the **6G position** particularly difficult.

PRACTICE 32-34

Stringer Bead, 6G Position

Using a properly lit and adjusted torch, one clean piece of pipe with a diameter of approximately 2 in. (51 mm), and filler metal, you will make a stringer bead around the pipe with the pipe in the 6G position.

Start at the bottom and weld upward toward the top of the pipe, **Figure 32-72**. The weld bead shape will change as you move around the pipe. To prevent the bottom from pulling to one side and slight movement to the high side, the side movement will create a shelf to hold the metal in place.

The side of the bead will pull to one side, but not as severely as at the bottom. To keep the side from being pulled out of shape, simply add the filler metal on the high side of

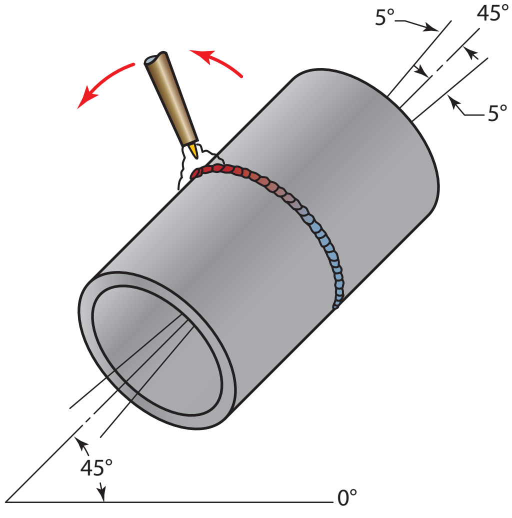

FIGURE 32-71 6G position. The pipe is inclined at a 45° angle.

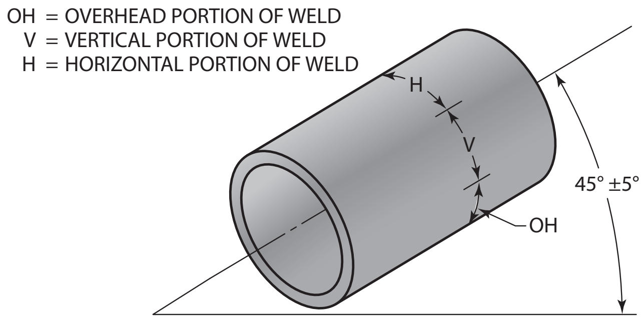

FIGURE 32-72 6G position.

the joint. Some side movement may be required, but not as much as for the bottom.

The top will pull down to one side and tend to be flatter than the other parts of the bead, especially along the side of the pipe. To prevent one-sidedness, the filler metal is added to the top side. To add to the buildup of the bead, change the torch angle or the flame height.

Repeat this weld until it can be made straight and uniform in width and reinforcement. Turn off the cylinders, bleed the hoses, back out the regulator adjusting screws, and clean your work area when you are finished.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 32-35

Butt Joint, 6G Position

Using a properly lit and adjusted torch, one clean piece of pipe approximately 2 in. (51 mm) in diameter, and filler metal, you will weld a butt joint in the 6G position. The pipe ends should be beveled and tack welded together. Secure the pipe at a 45° angle and start welding. Repeat this weld until it can be made without defects. Turn off the cylinders, bleed the hoses, back out the regulator adjusting screws, and clean your work area when you are finished.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

THIN-WALL TUBING

Welding thin-wall tubing requires a technique similar to welding a stringer bead around pipe. If penetration is not a concern, then the welding proceeds as if you were making a stringer bead on pipe. However, if penetration is required, then the weld will probably have a **keyhole** to ensure 100% penetration, **Figure 32-73**. This will be similar to welding the root pass.

If you want to practice on tubing but it is not readily available, then 16-gauge sheet metal can be rolled up and tack welded. Because 16 gauge is a standard wall thickness for tubing, fabricating your own will give you a realistic experience.

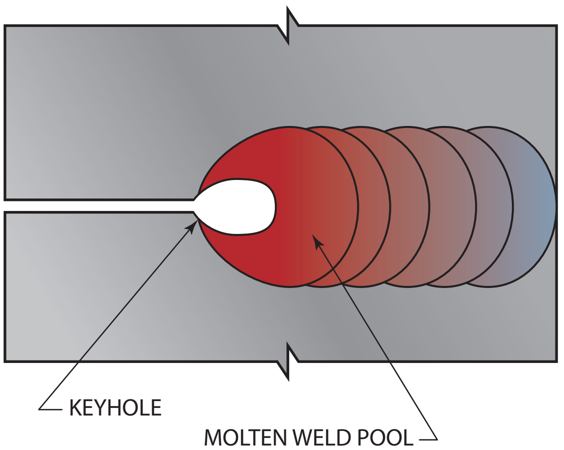

FIGURE 32-73 The key hole in the root of the joint helps to ensure 100% root penetration.

Summary

In an ideal world we would all have the correct tip size for every job we attempted; however, in reality, often the oxyfuel welding process is used for repair work when it is not possible to have an infinite selection of tip sizes. Learning to control the heat input to the weld by changing the torch angle, height, or travel speed is important so that you can produce satisfactory welds under these service conditions. It is not safe or recommended for you to turn down the flame below the tip's optimal operating capacity. Therefore, you must learn to control the heat by changing the angle, tip height, or travel speed.

Oxyacetylene welding is the process of preference for part-time and amateur welders. It allows them the greatest flexibility and is often the most forgiving. The most common problem OF welding presents is heat and weld distortion on large weldments. Because of the difficulty in controlling distortion and the time required to make large welds, other welding processes are often selected for such welds. That is not to say that large welds are not possible with OF welding; they just take more time and skill.

Review

1. What protects the molten weld pool from oxidation during a gas weld?
2. How does tip size affect a gas weld?
3. How does torch angle affect a gas weld?
4. How does welding rod size affect a gas weld?
5. What is a good indication that the molten weld pool is not being protected from oxidation?
6. Why should the end of the gas filler rod be bent?
7. What is the purpose of a heat sink?
8. Why should the end of the welding rod be kept inside the flame envelope?
9. Does a weld have to have 100% penetration to be strong?
10. What technique can be used to minimize weld distortion on a flat butt joint?
11. Why does the edge of the top plate on a lap joint tend to melt more easily?
12. What is meant by the term *out-of-position?*
13. What holds the molten weld pool in place on a vertical weld?
14. What additional personal safety protection should be used for overhead welds?
15. What force holds the molten weld pool in place on an overhead weld?
16. What is the welding sequence for a 1G pipe weld?
17. What is the proper method for stopping a weld pool so it can be easily restarted?
18. What welding positions are required when making a 5G weld on pipe?
19. What welding positions are required when making a 6G weld on pipe?
20. How can 100% penetration be ensured when making welds on thin-wall tubing?

Chapter 33

Brazing, Braze Welding, and Soldering

OBJECTIVES

After completing this chapter, the student should be able to

- define the terms *brazing, braze welding*, and *soldering*.
- explain the advantages and disadvantages of liquid-solid phase bonding.
- demonstrate an ability to properly clean, assemble, and perform required practice joints.
- describe the functions of fluxes in making proper liquid-solid phase bonded joints.

KEY TERMS

braze buildup
braze welding
brazing
brazing alloys
capillary action
corrosion resistance
dip brazing
ductility
elastic limit
eutectic composition
fatigue failures
fatigue resistance
fluxes
furnace brazing
induction
liquid-solid phase bonding processes
low-fuming alloys
paste range
phase
resistance brazing
shear strength
silver braze
soldering
soldering alloys
tensile strength
torch

INTRODUCTION

Brazing and soldering are both classified by the American Welding Society as **liquid-solid phase bonding processes**. Liquid means that the filler metal is melted; solid means that the base material or materials are not melted. The **phase** is the temperature at which bonding takes place between the solid base material and the liquid filler metal. The bond between the base material and filler metal is a metallurgical bond because no melting or alloying of the base metal occurs. If done correctly, this bond results in a joint having four- or five-times the tensile strength of that of the filler metal itself.

The only difference between brazing and soldering is the temperature at which each process takes place. Because only the temperature separates the two processes, it is possible to do both brazing and soldering using different mixtures of the same base metal, depending on the alloys used and their melting temperatures. For example, you can silver braze and silver solder depending on the alloy. Even

within a single alloy, such as silver solder, there are alloys that melt at different temperatures. A jeweler building a special piece such as a silver ring can start the assembly using a higher-temperature silver solder, and then use a slightly lower-temperature solder compound for each additional piece added. That way there is no chance that the first high-temperature soldered pieces will melt as the next pieces are added using a lower-temperature solder.

BRAZING, BRAZE WELDING, AND SOLDERING

Brazing is divided into two major categories, brazing and braze welding.

Brazing

Brazing occurs at a temperature above 840°F (450°C), and the parts being joined must be fitted so that the joint spacing is very small, approximately 0.025 in. (0.6 mm) to 0.002 in. (0.06 mm), **Figure 33-1**. This small spacing allows capillary action to draw the filler metal into the joint when the parts reach the proper phase temperature.

Capillary action is the force that pulls water up into a paper towel or pulls a liquid into a very fine straw, **Figure 33-2**.

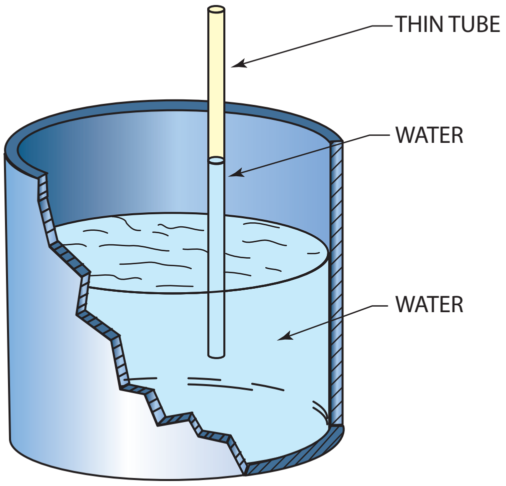

FIGURE 33-2 Capillary action pulls water into a thin tube.

Braze Welding

Braze welding can be done with the same brazing alloys as brazing, so the only difference is it does not need capillary action to pull filler metal into the joint. Examples of brazing and braze welding joint designs are shown in **Figure 33-3**.

Soldering

Soldering takes place at temperatures below 840°F (450°C). The soldering process may or may not use capillary action to pull the solder into the joint. When capillary action does occur, just like brazing, the joint strength increases several times greater than the solder itself.

ADVANTAGES OF BRAZING AND SOLDERING

Some advantages of brazing and soldering as compared to other methods of joining include the following:

- Low temperature—Because the base metal does not have to melt, a low-temperature heat source can be used.
- May be permanently or temporarily joined—Because the base metal is not damaged, parts may be disassembled at a later time by simply reapplying heat. The parts then can be reused. However, the joint is solid enough to be permanent, **Figure 33-4**.
- Dissimilar materials can be joined—It is easy to join dissimilar metals, such as copper to steel, aluminum to brass, and cast iron to stainless steel, **Figure 33-5**. It is also possible to join nonmetals to each other or nonmetals to metals. Ceramics are easily brazed to each other or to metals.
- Speed of joining
  a. Parts can be preassembled and dipped or furnace soldered or brazed in large quantities, **Figure 33-6**.
  b. A lower temperature means less time in heating.
- Less chance of damaging parts—A heat source can be used that has a maximum temperature below the temperature that may cause damage to the parts. With the controlled temperature sufficiently low, even if lower skilled workers are doing the work, there is little to no chance of damaging parts, **Figure 33-7**.

FIGURE 33-1 A brazed lap joint (A) and a braze welded lap joint (B).

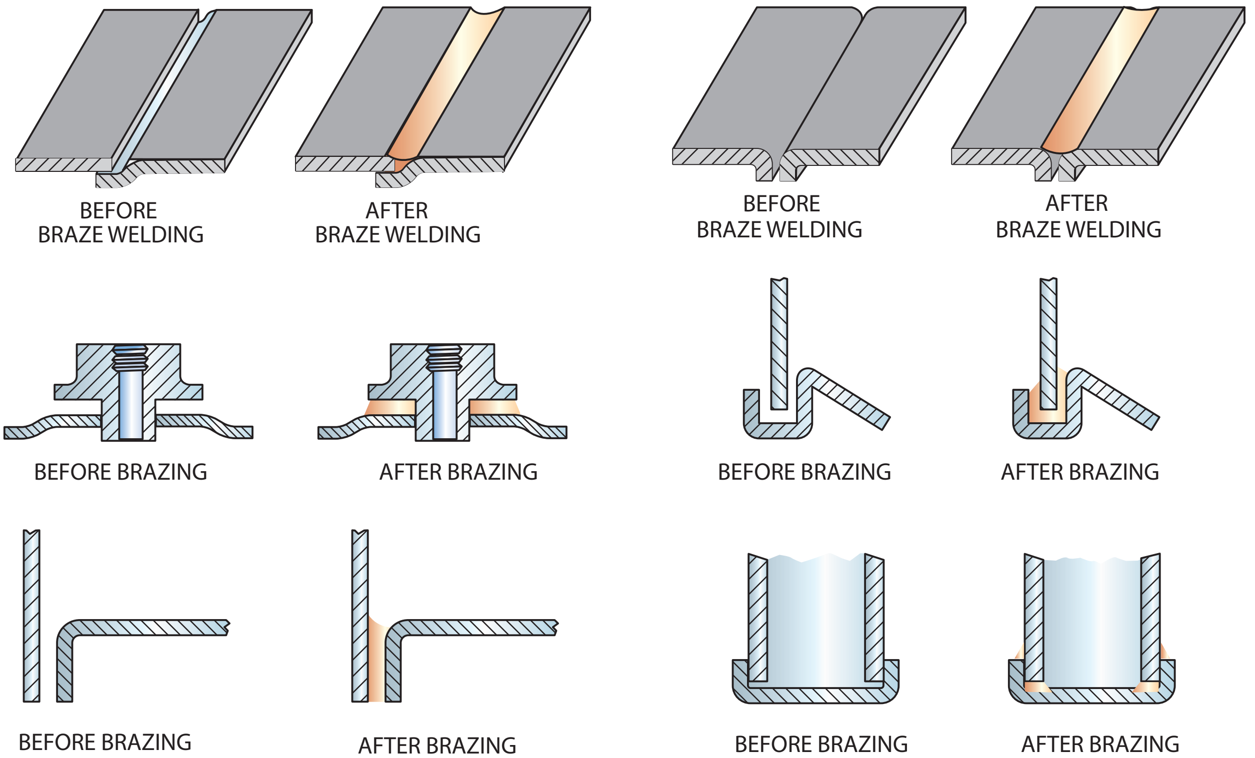

FIGURE 33-3 Examples of brazing and braze welded joints.

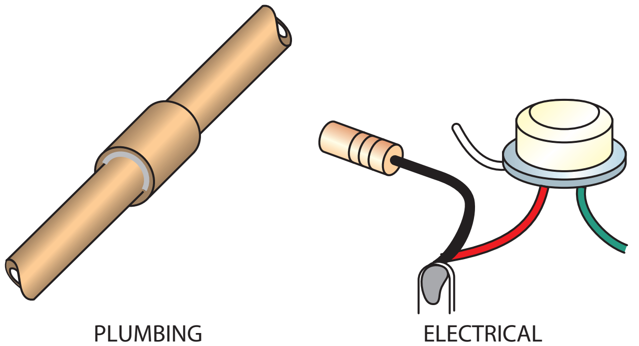

FIGURE 33-4 Examples of permanent joints that can be easily disassembled and the parts can be reused.

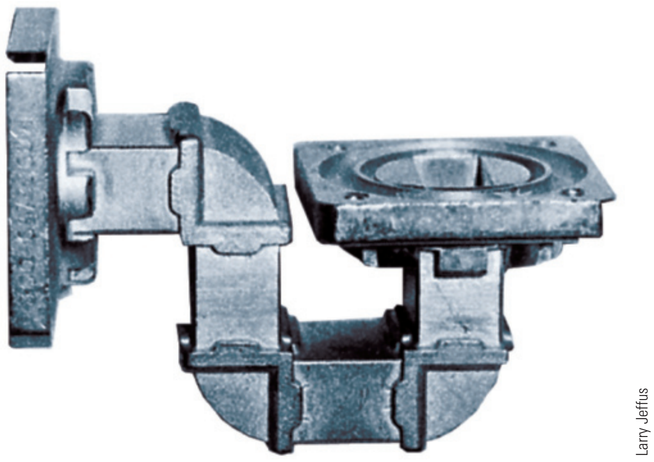

FIGURE 33-6 Furnace brazed part.

- Slow rate of heating and cooling—Because it is not necessary to heat a small area to its melting temperature and then allow it to cool quickly to a solid, the internal stresses caused by rapid temperature changes can be reduced.
- Parts of varying thicknesses can be joined—Very thin parts or a thin part and a thick part can be joined without burning or overheating them.
- Easy realignment—Parts can be realigned easily by reheating the joint and then repositioning the part.

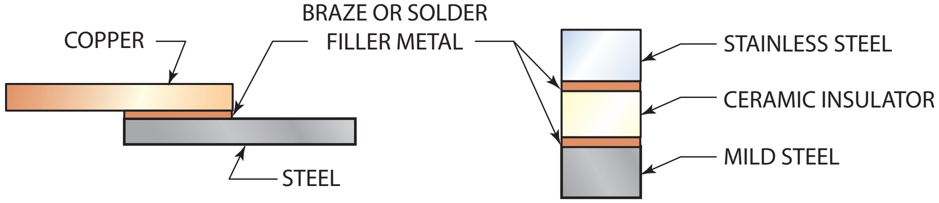

FIGURE 33-5 Dissimilar materials joined.

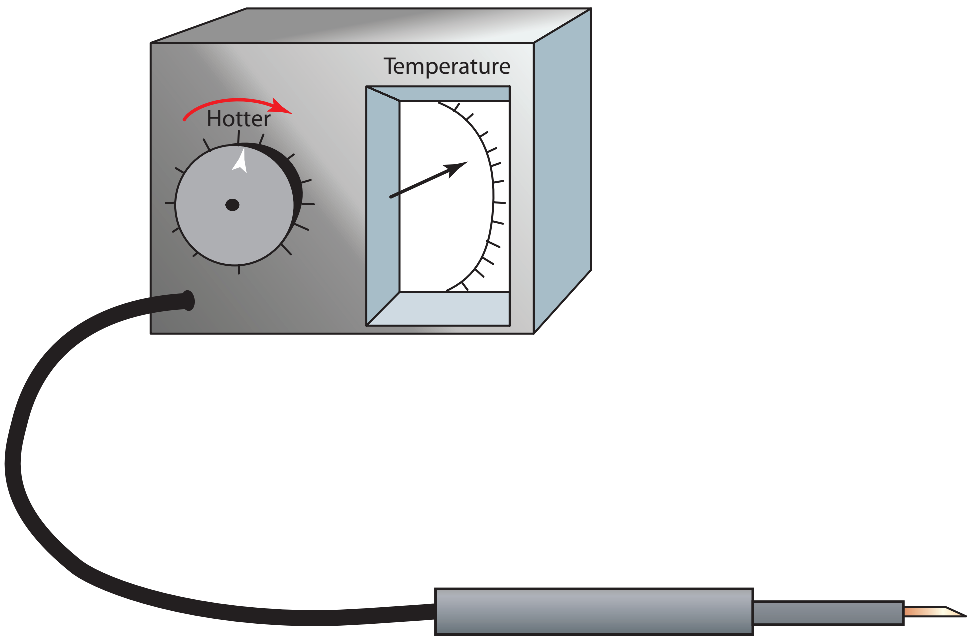

FIGURE 33-7 Control console for resistance soldering.

PHYSICAL PROPERTIES OF THE BRAZED OR SOLDERED JOINT

Tensile Strength

Tensile strength of a joint is its ability to withstand being pulled apart, **Figure 33-8**. A brazed joint can be made that has a tensile strength four- to five-times higher than the filler metal itself. If a few drops of water are placed between two smooth and flat panes of glass and the panes are pressed together, then a tensile load is required to pull the panes of glass apart. The water, which has no tensile strength itself, has added tensile strength to the glass joint.

The glass is being held together by the surface tension of the water. As the space between the pieces of glass decreases, the tensile strength increases. The same action takes place with a brazed or soldered joint. As the joint spacing decreases, the surface tension increases the tensile strength of the joint, **Table 33-1**.

Shear Strength

Shear strength of a joint is its ability to withstand a force parallel to the joint, **Figure 33-9**. For a solder or braze joint, the shear strength depends on the amount of overlapping area of the base parts. The greater the area that is overlapped, the greater is the strength.

FIGURE 33-8 Joint in tension.

Ductility

Ductility of a joint is its ability to bend without failing. Most brazing and soldering alloys are ductile metals, so the joint made with these alloys is also ductile.

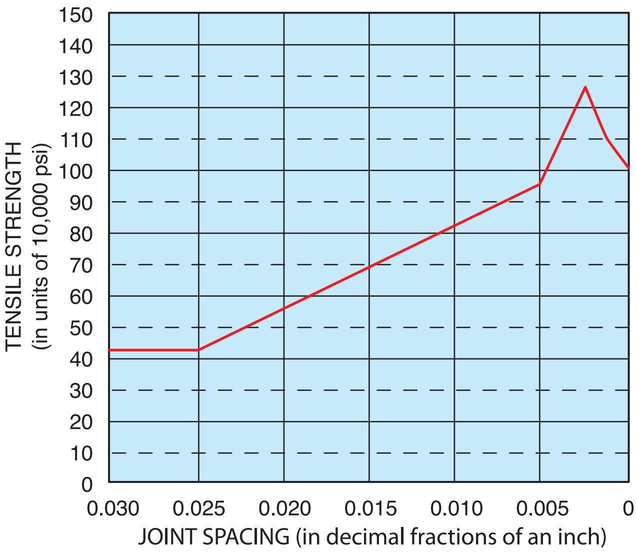

TABLE 33-1 Tensile Strength of Brazed Joint Increases as Joint Space Decreases

Fatigue Resistance

Fatigue resistance of a metal is its ability to be bent repeatedly without exceeding its **elastic limit** and without failure. For most soldered or brazed joints, fatigue resistance is usually fairly low. As a joint is bent, the

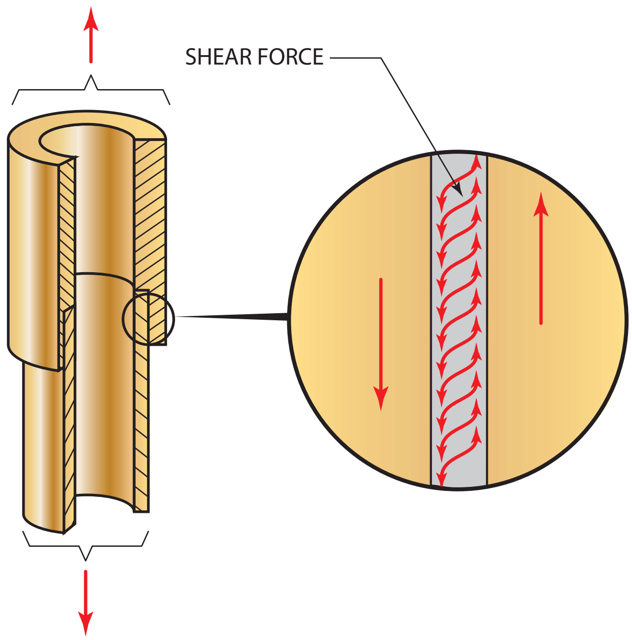

FIGURE 33-9 Effect of shear on a joint.

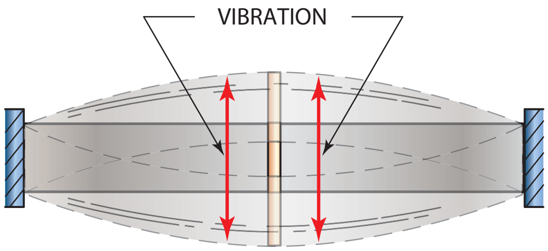

FIGURE 33-10 A joint being cyclically bent.

less ductile base materials cause a shear force to be applied to the filler metal, **Figure 33-10**, resulting in joint failure. **Fatigue failures** may also occur as a result of vibration.

Corrosion Resistance

Corrosion resistance of a joint is its ability to resist chemical attack. The compatibility of the base materials to the filler metal will determine the corrosion resistance. Using the proper filler metal with the base materials that are listed in this chapter will result in corrosion-free joints. However, using filler metals on base materials that are not recommended in this chapter may result in a joint that looks good when completed but will eventually corrode. For example, a brass brazing rod that contains copper (Cu) and zinc (Zn) (BCuZn) will make a nice-looking joint on stainless steel. But the zinc in the brass will combine with the nickel in the stainless steel if the part is kept hot for too long. As a result, a brittle structure is formed in the joint, reducing strength.

FLUXES USED IN BRAZING, BRAZE WELDING, AND SOLDERING

Flux

Fluxes used in brazing and soldering have three major functions:

- They must remove any oxides that form as a result of heating the parts.
- They must promote wetting, which is the phenomenon whereby a liquid filler metal or flux spreads and adheres in a thin, continuous layer on a solid base metal. In soldering the process is often called tinning.
- They should aid in capillary action by pulling the molten alloy into the joint.

The flux, when heated to its reacting temperature, must be thin and flow through the gap provided at the joint. As it flows through the joint, the flux dissolves and absorbs oxides, allowing the molten filler metal to be pulled in behind it, **Figure 33-11**. After the joint is complete, the flux residue should be removed.

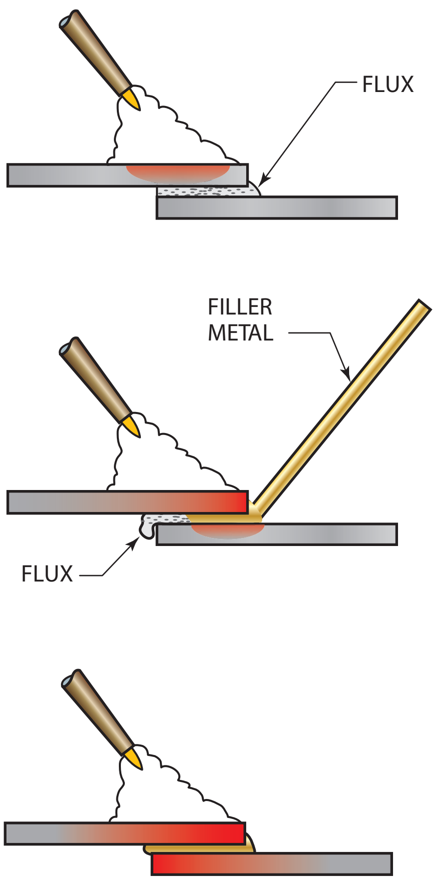

FIGURE 33-11 Flux flowing into a joint reduces oxides to clean the surfaces and gives rise to a capillary action that causes the filler metal to flow behind it.

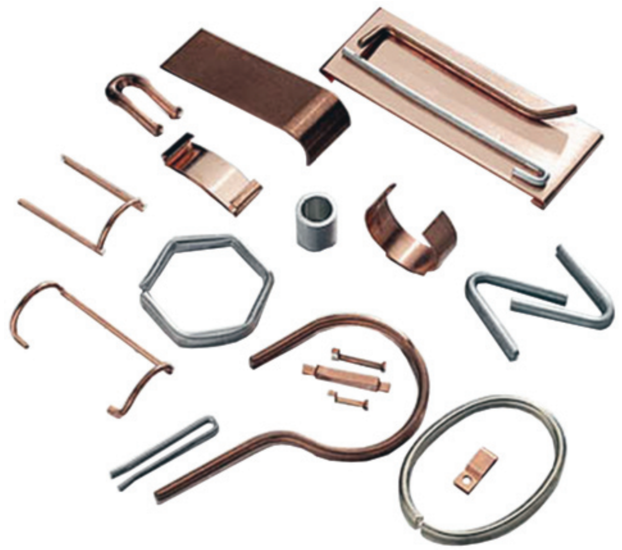

FIGURE 33-12 Braze/solder forms that can be preplaced in a braze/solder joint.

FIGURE 33-14 Gun for injecting flux into joint.

FIGURE 33-15 Tubes that contain flux filler metal mixtures.

Forms of Fluxes

Fluxes are available in many forms, such as solids, powders, pastes, liquids, sheets, rings, and washers, **Figure 33-12**. They are also available mixed with the filler metal, inside the filler metal, or on the outside of the filler metal, **Figure 33-13**. Sheets, rings, and washers may be placed within the joints of an assembly before heating so that a good bond inside the joint can be ensured. Paste and liquids can be injected into a joint from tubes using a special gun, **Figure 33-14**. Paste, powders, and liquids may be brushed on the joint before or after the material is heated. Paste and powders may also be applied to the end of the rod by heating the rod and dipping it in the flux. Most powders can be made into a paste, or a paste can be thinned by adding distilled water or alcohol; see manufacturers' specifications for details. If water is used, it should be distilled because tap water may contain minerals that will weaken the flux.

Some liquid fluxes may also be added to the gas when using an oxyfuel gas **torch** for brazing or soldering. The flux is picked up by the fuel gas as it is bubbled through the flux container and is then carried to the torch where it becomes part of the flame.

Flux and filler metal combinations are the most convenient and easy to use, **Figure 33-15**. It may be necessary to stock more than one type of flux-filler metal combination for different jobs. These combinations are more expensive than buying the filler and flux separately. In cases where the flux covers the outside of the filler metal, it may be damaged by humidity or chipped off during storage.

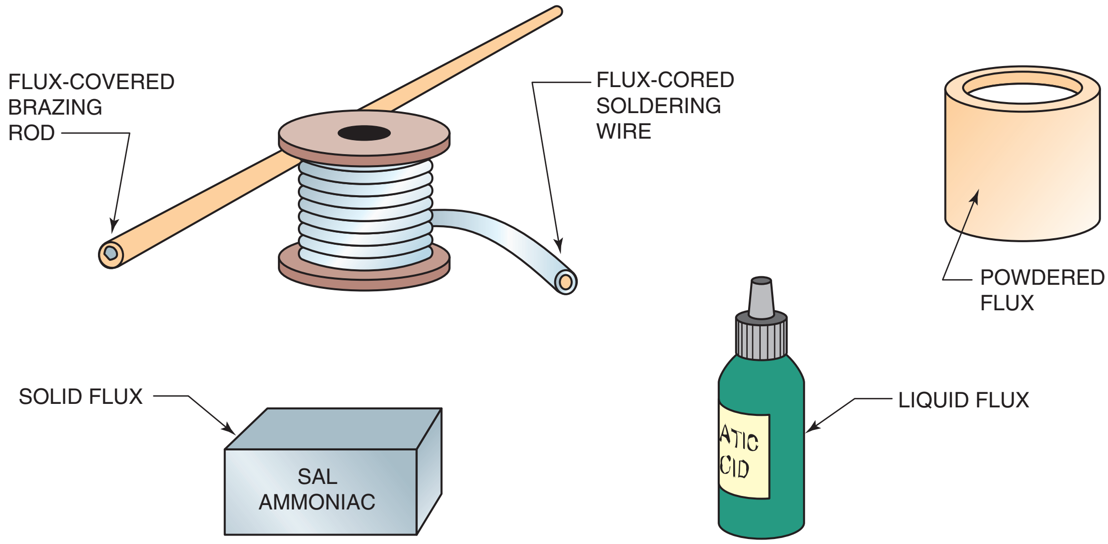

FIGURE 33-13 Flux can be purchased with the filler metal or separately.

THINK GREEN

Most of the fluxes used for brazing and soldering are not harmful to the environment. However, large quantities of even the most benign materials introduced accidentally or intentionally into the environment can cause damage. Even lemon juice, a common electronic soldering flux, in large enough quantities can cause harm to the environment. Before disposing of any soldering or brazing fluxes, read the material safety data sheet (MSDS) carefully and follow its recommended procedures. Keeping our environment clean and safe is everyone's responsibility.

Using excessive flux in a joint may result in flux being trapped in the joint, weakening the joint or causing the joint to leak or fail.

Fluxing Action

Brazing and soldering fluxes will remove light surface oxides, promote wetting, and aid in capillary action. The use of fluxes does not eliminate the need for good joint cleaning. Fluxes will not remove oil, dirt, paint, glues, heavy oxide layers, or other surface contaminants.

Soldering fluxes are chemical compounds such as muriatic acid (dilute hydrochloric acid), sal ammoniac (ammonium chloride), or rosin. Brazing fluxes are chemical compounds such as fluorides, chlorides, boric acids, and alkalies. These compounds react to dissolve, absorb, or mechanically break up thin surface oxides that are formed as the parts are being heated. They must be stable and remain active through the entire temperature range of the solder or braze filler metal. The chemicals in the flux react with the oxides as either acids or bases. Some fluxes that are heated to a liquid so the parts can be dipped into the liquid flux are salts.

The reactivity of a flux is greatly affected by temperature. As the parts are heated to the brazing or soldering temperature, the flux becomes more active. Some fluxes are completely inactive at room temperature. Most fluxes have a temperature range within which they are most effective. Care should be taken to avoid overheating fluxes. If they become overheated or burned, then they will stop working as fluxes, and they become a contamination in the joint. If overheating has occurred, then the welder must stop and clean off the damaged flux before continuing.

Fluxes that are active at room temperature must be neutralized (made inactive) or washed off after the job is complete. If these fluxes are left on the joint, premature failure may result due to flux-induced corrosion. Fluxes that are inactive at room temperature do not have to be cleaned off the part. However, if the part is to be painted or if auto body plastic is to be applied, then fluxes must be removed.

BRAZING AND SOLDERING METHODS

Brazing and soldering methods are grouped according to the method with which heat is applied: torch, furnace, **induction**, dipped, or resistance.

Torch Brazing and Soldering

Oxyfuel or air fuel torches can be used either manually or automatically, **Figure 33-16**. Acetylene is often used as the fuel gas, but it is preferable to use one of the other fuel gases with a higher heat level in the secondary flame, **Figure 33-17**. The oxyacetylene flame has a very high temperature near the inner cone, but it has little heat in the outer flame. This often results in the parts being overheated in a localized area. Fuel gases such as MAPP®, propane, butane, and natural gas have a flame that will heat parts more uniformly. Often torches are used that mix air with the fuel gas in a swirling or turbulent manner to increase the flame's temperature, **Figure 33-18**. The flame may even completely surround a small diameter pipe, heating it from all sides at once, **Figure 33-19**.

Some advantages of using a torch include the following:

- Versatility—Using a torch is the most versatile method. Both small and large parts in a wide variety of materials can be joined with the same torch.

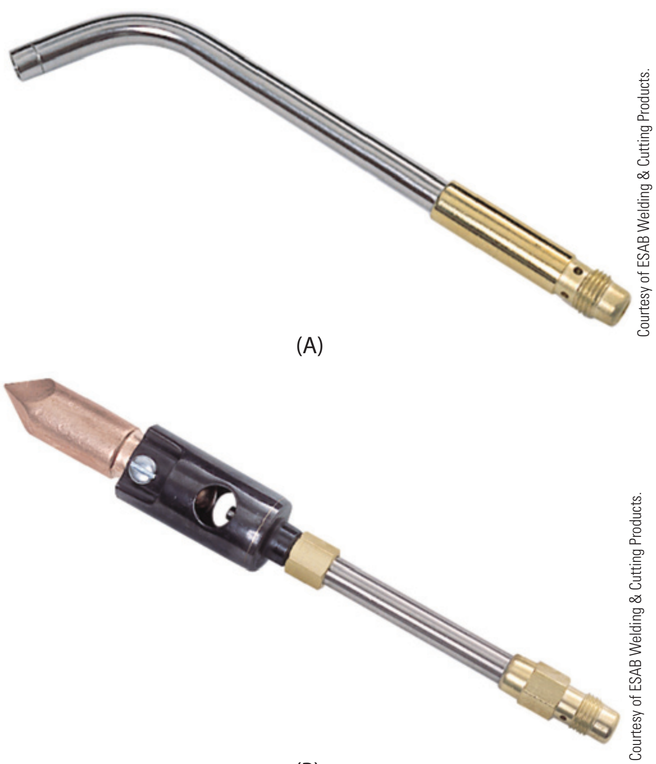

FIGURE 33-16 An air propane torch can be used in soldering joints. (A) Using a flame directly. (B) Using a flame to heat a soldering copper.

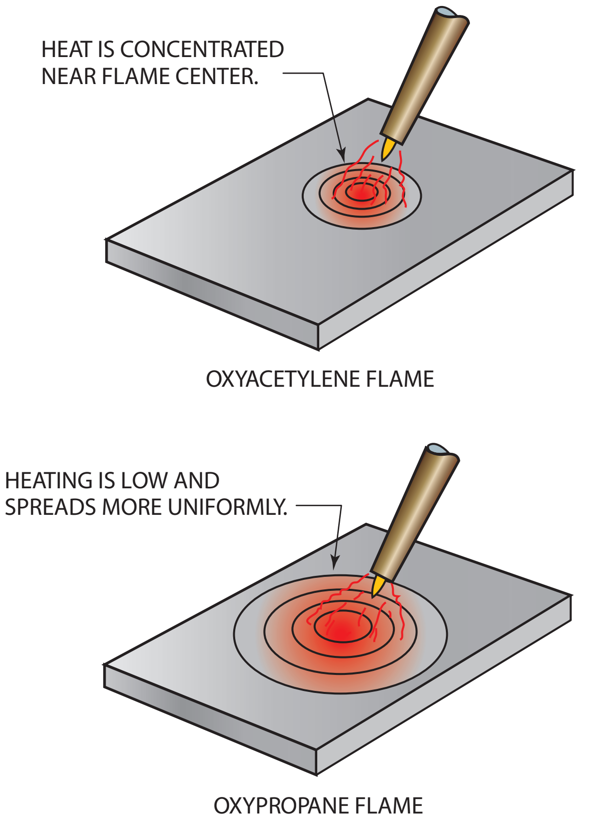

FIGURE 33-17 The high temperature of an oxyacetylene flame may cause localized overheating.

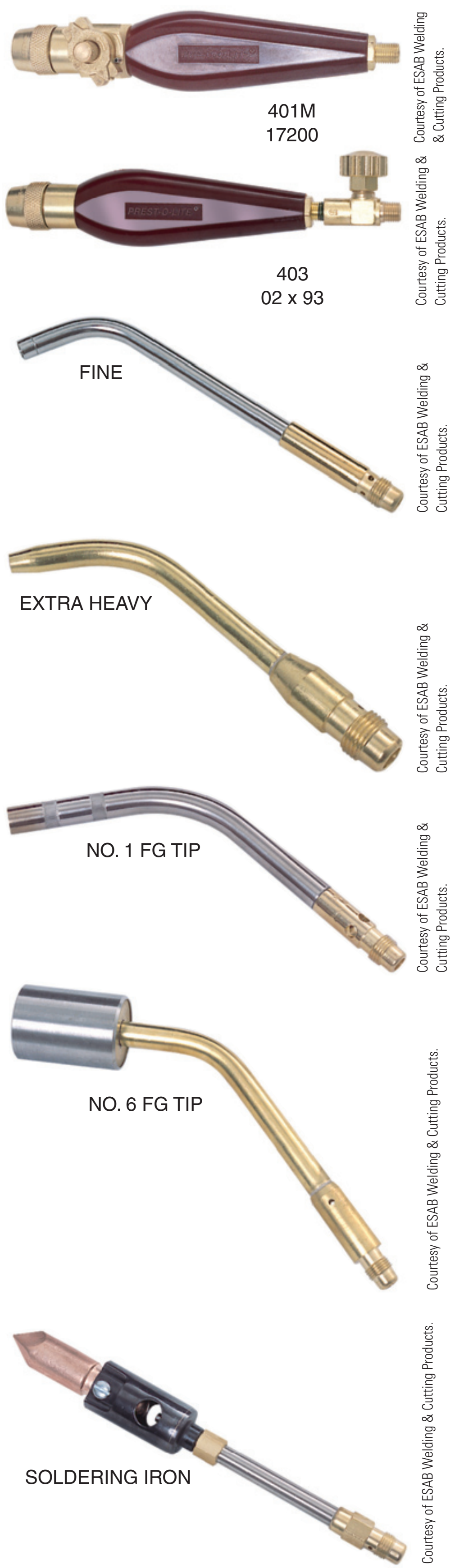

FIGURE 33-18 Examples of torch tips and handles that use air-fuel mixtures for brazing.

- Portability—A torch is very portable. Any place a set of cylinders can be taken or anywhere the hoses can be pulled into can be soldered or brazed with a torch.
- Speed—The flame of the torch is one of the quickest ways of heating the material to be joined, especially on thicker sections.

Some of the disadvantages of using a torch include the following:

- Overheating—When using a torch, it is easy to overheat or burn the parts, flux, or filler metal.
- Skill—A high level of skill with a torch is required to produce consistently good joints.
- Fires—It is easy to start a fire if a torch is used around combustible (flammable) materials.

Furnace Brazing and Soldering

In the **furnace brazing** and soldering method the parts are heated to their brazing or soldering temperature by passing them through or putting them into a furnace. The furnace may be heated by electricity, oil, natural gas, or any other locally available fuel. The parts may be passed through the furnace on a conveyor belt in trays or placed on the belt itself, **Figure 33-20**. The parts also may be loaded in trays

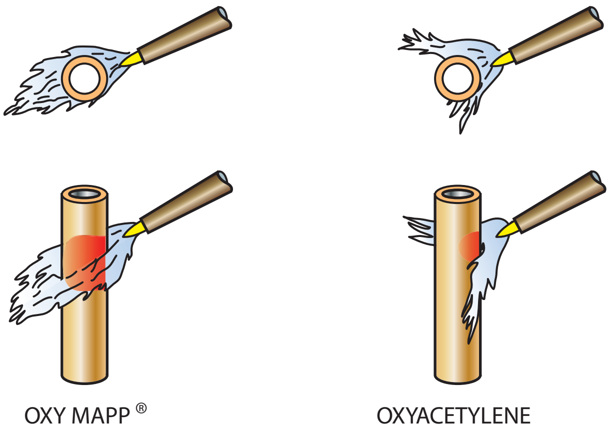

FIGURE 33-19 Heating characteristics of oxy MAPP® compared with oxyacetylene on round materials.

to be placed in a furnace that does not use a conveyor belt, **Figure 33-21**.

Some of the advantages of using a furnace include the following:

- Temperature control—The furnace temperature can be accurately controlled to ensure that the parts will not overheat.
- Controlled atmosphere—The furnace can be filled with an inert gas to prevent oxides from forming on the parts.
- Uniform heating—The uniform heating of the parts reduces stresses and distortion.
- Mass production—By using a furnace, it is easy to produce a high quantity of parts.

Some of the disadvantages of using a furnace include the following:

- Size—Unless parts are small, the length of time required to heat them is extremely long.
- Heat damage—The entire part must be able to withstand heating without burning.

FIGURE 33-21 Small furnace brazed part.

Induction Brazing and Soldering

The induction method of heating uses a high-frequency electrical current to establish a corresponding current on the surface of the part, **Figure 33-22**. The current on the part causes rapid and very localized heating of the surface only. There is little, if any, internal heating of the part except by conductivity of heat from the surface.

Advantages of the induction method are the following:

- Speed—Very little time is required for the part to reach the desired temperature.

Some of the disadvantages of the induction method include the following:

- Distortion—The very localized heating may result in some distortion.

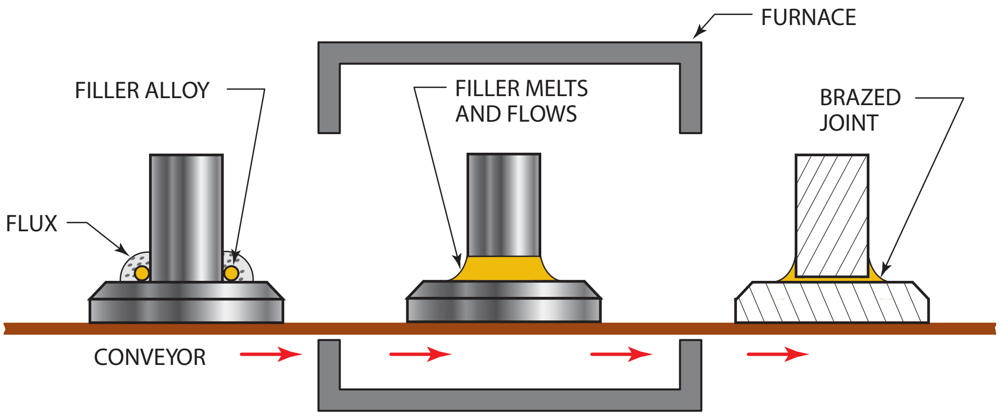

FIGURE 33-20 Furnace brazing permits the rapid joining of parts on a production basis.

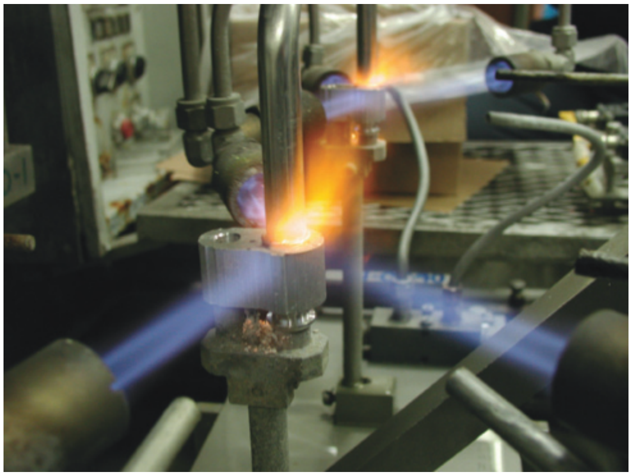

FIGURE 33-22 Induction brazing and soldering machine.

- Lack of temperature control—The electrical resistance of the part increases as the part heats up. This, in turn, increases the temperature produced.
- Incomplete penetration—Because the inside of the part is not directly heated, it may be too cool to permit the filler metal to flow fully through the joint.

Dip Brazing and Soldering

Two types of **dip brazing** or soldering are used: molten flux bath and molten metal bath. With the molten flux method, the brazing or soldering filler metal in a suitable form is preplaced in the joint, and the assembly is immersed in a bath of molten flux, as shown in **Figure 33-23**. The bath supplies the heat needed to preheat the joint and fuse the solder or braze metal, and it provides protection from oxidation.

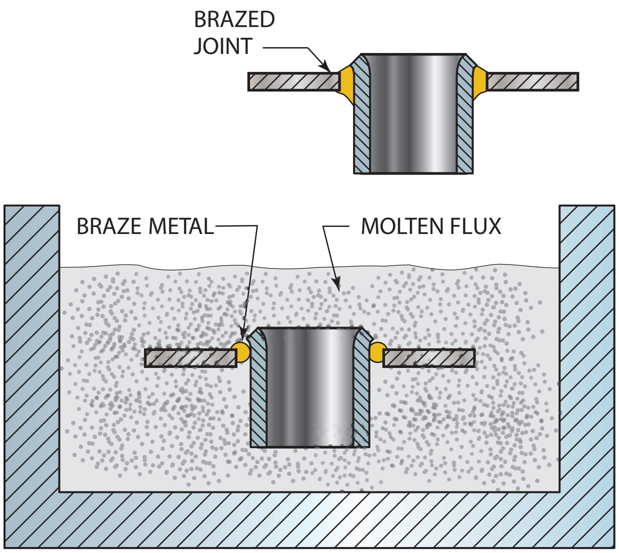

FIGURE 33-23 Dip brazing eliminates the need for a separate fluxing operation.

With the molten metal method, the prefluxed parts are immersed in a bath of molten braze or solder metal, which is protected by a cover of molten flux. This method is confined to wires and other small parts. Once they are removed from the bath, the ends of the wires and parts must not be allowed to move until the solder or braze metal has solidified. As with all brazing or soldering operations, any movement of the parts as they cool from a liquid through the paste range to become a solid will result in microfractures in the filler metal. In electronic parts these microfractures cause resistance to the electron flow and may render the part unfit for service. Reheating can be used to re-fuse the joint only if reheating will not damage the part beyond use.

Some of the advantages of dip processing include the following:

- Mass production—It is possible to dip many small parts at one time.
- Corrosion protection—The entire surface of the part can be covered with the filler metal at the same time that it is being joined. If a corrosion-resistant filler metal is used, then the thin layer provided will help protect the part from corrosion.
- Distortion minimized—The entire part is heated uniformly, which reduces distortion.

Some of the disadvantages of dip processing include the following:

- Steam explosions—Moisture trapped in the joint may cause a steam explosion that can scatter molten metal.
- Corrosion—If any of the salt is trapped in the joint or is left on the surface, then corrosion may cause the part to fail at some time in the future.
- Size—Parts must be small to be effectively joined.
- Quantity—Only a large quantity of parts can justify heating the large amount of molten filler metal or salt required for dipping.

Resistance Brazing and Soldering

The resistance method of heating uses an electric current that is passed through the part. The resistance of the part to the current flow results in the heat needed to produce the bond. The flux is usually preplaced, and the material must have sufficient electrical resistance to produce the desired heating. The machine used in this method resembles a spot welder.

Some of the advantages of the resistance heating method include the following:

- Localized heating—The heat can be localized so that the entire part may not have to be heated.
- Speed—A wide variety of spots can be made on the same machine without having to make major adjustments on the machine.
- Multiple spots—Many spots can be joined in a small area without disturbing joints that are already made.

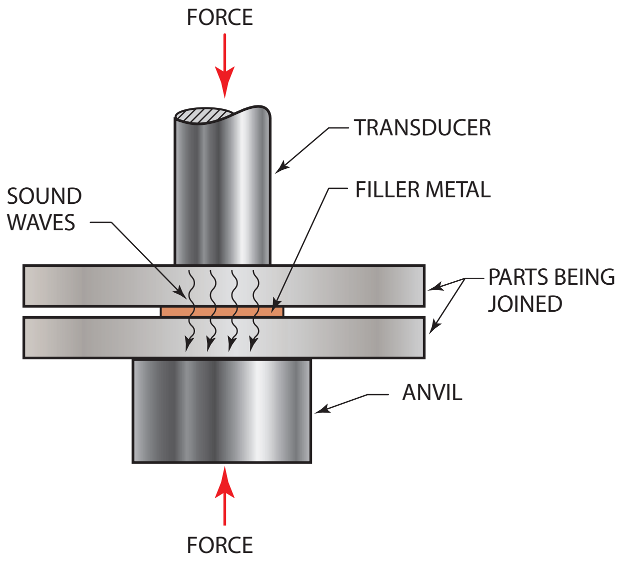

FIGURE 33-24 Ultrasonic bonding.

Some of the disadvantages of the resistance heating method include the following:

- Distortion—Localized heating may result in distortion.
- Conductors—Parts must be able to conduct electricity.
- Joint design—Lap joints in plate are the only joint designs that can be made.

Special Methods

A few other methods of producing soldered or brazed parts are used that do not entirely depend on heat to produce the joint. The ultrasonic method uses high-frequency sound waves to produce the bond or to aid with heat in the bonding, **Figure 33-24**. Another method is diffusion, which uses pressure and may use heat or ultrasound to form a bond. Still another process uses infrared light to heat the part for brazing or soldering.

FILLER METALS

Types of Filler Metals

The type of filler metal used for any specific joint should be selected by considering as many of the criteria listed in **Figure 33-25** as possible. It would be impossible to consider each of these items with the same importance. Welders must decide which things they feel are the most important and then base their selection on that decision.

Brazing and soldering metals are alloys—that is, a mixture of two or more metals. Each alloy is available in a variety of percentage mixtures. Some mixtures are stronger, and some melt at lower temperatures than other mixtures. Each one has specific properties. Almost all

- Material being joined
- Strength required
- Joint design
- Availability and cost
- Appearance
- Service (corrosion)
- Heating process to be used
- Cost

FIGURE 33-25 Criteria for selecting filler metal.

of the alloys used for brazing or soldering have a paste range. A ***paste range*** is the temperature range in which a metal is partly solid and partly liquid as it is heated or cooled. As the joined part cools through the paste range, it is important that the part is not moved. If the part is moved, then the solder or braze metal may crumble like dry clay, destroying the bond. The surface of a braze or solder alloy on a part that moved while it was in its paste range may look rough or have an unusually dull appearance.

EXPERIMENT 33-1

Paste Range

This experiment shows the effect on bonding of moving a part as the filler metal cools through its paste range. The experiment also shows how metal can be "worked" using its paste range. You will need tin-lead solder composed of 20% to 50% tin, with the remaining percentage being lead. You also will need a properly lit and adjusted torch, a short piece of brazing rod, and a piece of sheet metal. Using a hammer, make a dent in the sheet metal approximately the size of a quarter (25¢), **Figure 33-26**.

In a small group, watch the effects of heating and cooling solder as it passes through the paste range. Using the torch, melt a small amount of the solder into the dent and allow it to harden. Remelt the solder slowly, frequently flashing the torch off and touching the solder with the brazing rod until it is evident the solder has all melted. Once the solder has melted, stick the brazing rod in the solder and remove the torch. As the solder cools, move the brazing rod in the metal and observe what happens, **Figure 33-27**.

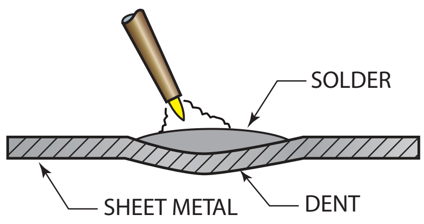

FIGURE 33-26 Partially fill the dent with solder.

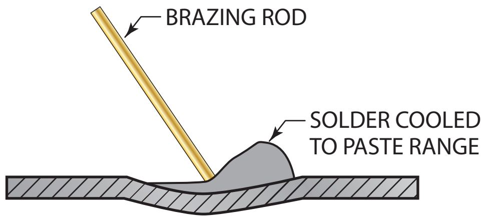

FIGURE 33-27 Solder being shaped as it cools to its paste range.

As the solder cools to the uppermost temperature of its paste range, it will have a rough surface appearance as the rod is moved. When the solder cools more, it will start to break up around the rod. Finally, as it becomes a solid, it will be completely broken away from the rod.

Now slowly reheat the solder and work the surface with the rod until it can be shaped like clay. If the surface is slightly rough, then a quick touch of the flame will smooth it. This is the same way in which "lead" is applied to some body panel joints on a new car so that the joints are not seen on the car when it is finished. The lead used is actually a tin-lead alloy or solder. A large area can be made as smooth as glass without sanding by simply flashing the area with the flame.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

SOLDERING ALLOYS

Soldering alloys are usually identified by their major alloying elements. **Table 33-2** lists the major types of solder and the materials they will join. In many cases, a base material can be joined by more than one solder alloy. In addition to the considerations for selecting filler metal listed in Figure 33-25, specific factors are listed in the following sections for the major soldering alloys.

Tin-Lead

Tin-lead is an alloy of 61.9% tin and 38.1% lead that melts at 362°F (183°C) and has no paste range. This is the **eutectic composition** (lowest possible melting point of an alloy) of the tin-lead solder. An alloy of 60% tin and 40% lead is commercially available and is close enough to the eutectic alloy to have the same low melting point with only a 12°F (7.8°C) paste range. The widest paste range is 173°F (78°C) for a mixture of 19.5% tin and 80.5% lead. This mixture begins to solidify at 535°F (289°C) and is totally solid at 362°F (193°C). The closest mixture that is commercially available is a 20% tin and 80% lead alloy. **Table 33-3** lists the percentages, temperatures, and paste ranges for tin-lead solders. Tin-lead solders are most commonly used on electrical connections but must never be used for water piping. Most health and construction codes will not allow tin-lead solders for use on water or food-handling equipment.

Tin-lead	Copper and copper alloys Mild steel Galvanized metal
Tin-antimony	Copper and copper alloys Mild steel
Cadmium-silver	High strength for copper and copper alloys Mild steel Stainless steel
Cadmium-zinc	Aluminum and aluminum alloys

TABLE 33-2 Soldering Alloys

CAUTION

Tin-lead solders must not be used where lead could become a health hazard in things such as food and water.

Tin-Antimony

Tin-antimony of solder alloys has a higher tensile strength and lower creep than the tin-lead solders. The most common alloy is 95/5, 95% tin and 5% antimony. This is often referred to as "hard solder." This is the most common solder used in plumbing because it is lead-free. The use of "C" flux, which is a mixture of flux and small flakes of solder, makes it much easier to fabricate quality joints. This mixture of flux and solder will draw additional solder into the joint as it is added.

Cadmium-Silver

These solder alloys have excellent wetting, flow, and strength characteristics, but they are expensive. The silver in this solder helps improve wetting and strength. Cadmium-silver alloys melt at a temperature of approximately 740°F (393°C); they are called high-temperature solders because they retain their strength at temperatures above most other solders. These solder alloys can be used to join aluminum to itself or other metals, for example, to copper piping that is used in air-conditioning equipment.

CAUTION

When silver soldering on food-handling equipment, use a cadmium-free silver solder.

CAUTION

If cadmium is overheated, the fumes can be hazardous unless the area is properly ventilated.

Cadmium-Zinc

Cadmium-zinc alloys have good wetting action and corrosion resistance on aluminum and aluminum alloys. The melting temperature is high, and some alloys have a wide paste range, **Table 33-4**.

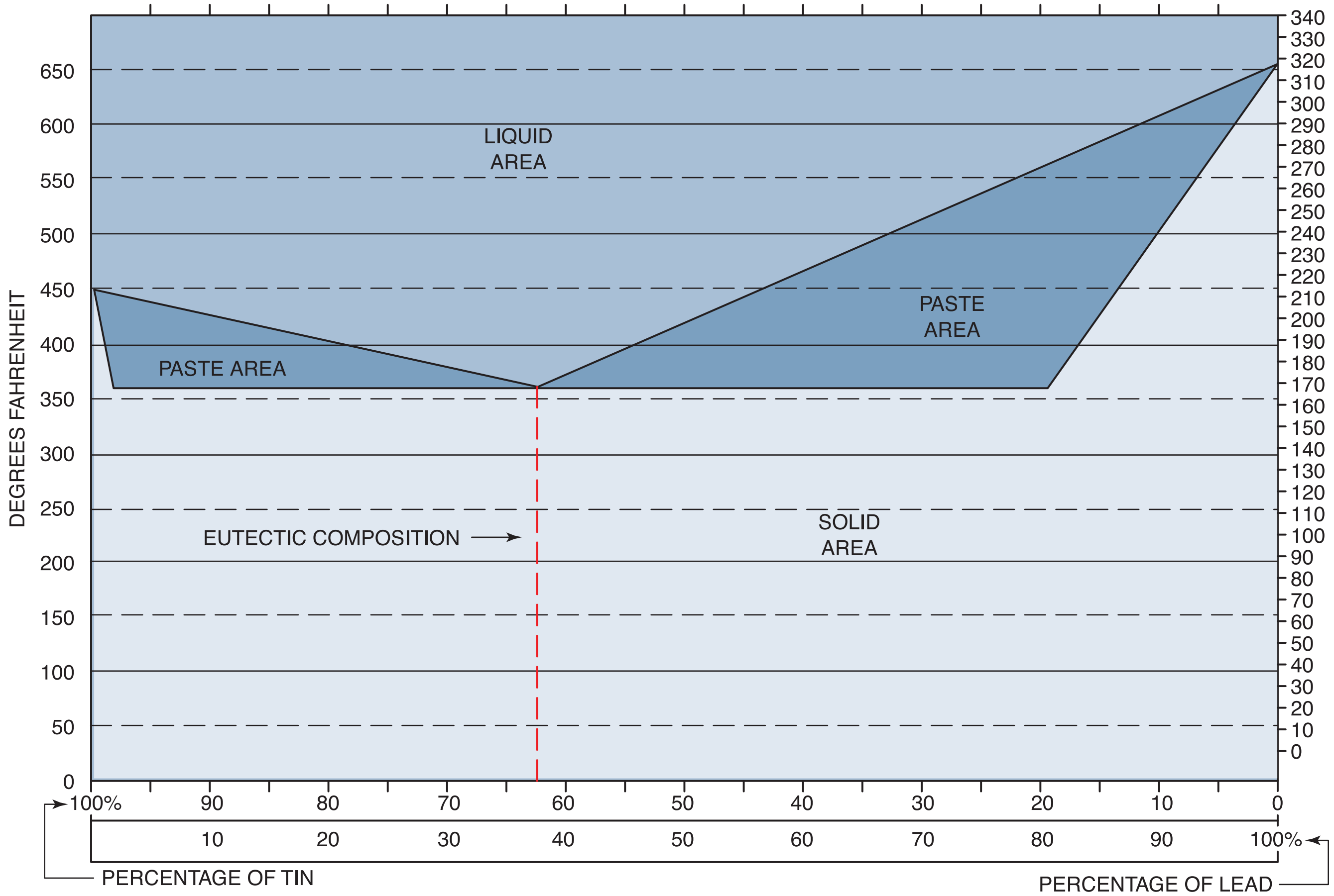

TABLE 33-3 Melting, Solidification, and Paste Range Temperatures for Tin-Lead Solders

Cadmium	Zinc	Completely Liquid	Completely Solid	Paste Range
82.5%	17.5%	509°F (265°C)	509°F (265°C)	No paste range
40.0%	60.0%	635°F (335°C)	509°F (265°C)	126°F (52°C)
10.0%	90.0%	750°F (399°C)	509°F (265°C)	241°F (116°C)

TABLE 33-4 Cadmium-Zinc Alloys

BRAZING ALLOYS

The American Welding Society's classification system for **brazing alloys** uses the letter *B* to indicate that the alloy is to be used for brazing. The next series of letters in the classification indicates the atomic symbol of metals used to make up the alloy, such as CuZn (copper and zinc). There may be a dash followed by a letter or number to indicate a specific alloyed percentage. The letter *R* may be added to indicate that the braze metal is in rod form. An example of a filler metal designation is BRCuZn-A, which indicates a copper-zinc brazing rod with 59.25% copper, 40% zinc, and 0.75% tin; **Table 33-5** is a list of the base metals and the most common alloys used to join the base metals. Not all of the available brazing alloys have an AWS classification. Some special alloys are known by registered trade names.

Copper-Zinc

Copper-zinc alloys are the most popular brazing alloys. They are available as regular and **low-fuming alloys**. The zinc in this braze metal has a tendency to burn out if it is overheated. Overheating is indicated by a red glow on the molten pool, which gives off a white smoke. The white smoke is zinc oxide. If zinc oxide is breathed in, it can cause zinc poisoning. Using a low-fuming alloy will help eliminate this problem. Examples of low-fuming alloys are RCuZn-B and RCuZn-C.

Base Metal	Brazing Filler Metal
Aluminum	BAlSi, aluminum silicon
Carbon steel	BCuZn, brass (copper-zinc) BCu, copper alloy BAg, silver alloy
Alloy steel	BAg, silver alloy BNi, nickel alloy
Stainless steel	BAg, silver alloy BAu, gold base alloy BNi, nickel alloy
Cast iron	BCuZn, brass (copper-zinc)
Galvanized iron	BCuZn, brass (copper-zinc)
Nickel	BAu, gold base alloy BAg, silver alloy BNi, nickel alloy
Nickel-copper alloy	BNi, nickel alloy BAg, silver alloy BCuZn, brass (copper-zinc)
Copper	BCuZn, brass (copper-zinc) BAg, silver alloy BCuP, copper-phosphorus
Silicon bronze	BCuZn, brass (copper-zinc) BAg, silver alloy BCuP, copper-phosphorus
Tungsten	BCuP, copper-phosphorus

TABLE 33-5 Base Metals and Common Brazing Filler Metals Used to Join the Base Metals

CAUTION

Breathing zinc oxide can cause zinc poisoning. If you think you have zinc poisoning, get medical treatment immediately.

Copper-Zinc and Copper-Phosphorus A5.8

The copper-zinc filler rods are often grouped together and known as brazing rods. The copper-phosphorus rods are referred to as phos-copper. Both terms do not adequately describe the metals in this group. There are vast differences among the five major classifications of the copper-zinc filler metals, as well as among the five major classifications of the copper-phosphorus filler metals. The following material describes the five major classifications of copper-zinc filler rods.

Class BRCuZn Class BRCuZn is used for the same application as BCu fillers. The addition of 40% zinc (Zn) and 60% copper (Cu) improves the corrosion resistance and aids in this rod's use with silicon-bronze, copper-nickel, and stainless steel.

CAUTION

Care must be exercised to prevent overheating this alloy because the zinc will vaporize, causing porosity and poisonous zinc fumes.

Class BRCuZn-A Class BRCuZn-A is commonly referred to as naval brass and can be used to fuse weld naval brass. The addition of 17% tin (Sn) to the alloy adds strength and corrosion resistance. The same types of metal can be joined with this rod as could be joined with BRCuZn.

Class BRCuZn-B Class BRCuZn-B is a manganese-bronze filler metal. It has a relatively low melting point and is free flowing. This rod can be used to braze weld steel, cast iron, brass, and bronze. The deposited metal is higher than BRCuZn or BRCuZn-A in strength, hardness, and corrosion resistance.

Class BRCuZn-C Class BRCuZn-C is a low-fuming, high-silicon (Si) bronze rod. It is especially good for general purpose work due to the low-fuming characteristic of the silicon on the zinc.

Class BRCuZn-D Class BRCuZn-D is a nickel-bronze rod with enough silicon to be low-fuming. The nickel gives the deposit a silver-white appearance and is referred to as white brass. This rod is used to braze and braze weld steel, malleable iron, and cast iron, and for building up wear surfaces on bearings.

Copper-Phosphorus

This alloy is sometimes referred to as phos-copper. It is a good alloy to consider for joints where silver braze alloys may have been used in the past. Phos-copper has good fluidity and wetability on copper and copper alloys. The joint spacing should be from 0.001 in. (0.03 mm) to 0.005 in. (0.12 mm) for the strongest joints. Heavy buildup of this alloy may cause brittleness in the joint. Phosphorus forms brittle iron phosphide at brazing temperatures on steel. Copper-phos or copper-phos-silver should not be used on copper-clad fittings with ferrous substrates because the copper can easily be burned off, exposing the underlying metal to phosphorus embrittlement.

The copper-phosphorus (BCuP group) rods are used in air-conditioning applications and in plumbing to join copper piping. The phosphorus makes the rod self-fluxing on copper. This feature is one of the major advantages of copper-phosphorus rods. The addition of a small amount of silver, approximately 2%, helps with wetting and flow into joints.

Class BCuP-1 Class BCuP-1 has a low wetting characteristic and a lower flow rate than the other phos-copper alloys. This type of filler metal should be preplaced in the joint. The major advantage of this type of filler metal is its increased ductility.

Classes BCuP-2 and BCuP-4 Classes BCuP-2 and BCuP-4 both have good flow into the joint. The high phosphorus content of the rods makes them self-fluxing on copper. Both of these classes are used often for plumbing installations.

Classes BCuP-3 and BCuP-5 Classes BCuP-3 and BCuP-5 both have high surface tension and low flow. They are used when close fit ups are not available.

Copper-Phosphorus-Silver

This alloy is sometimes referred to as sil-phos. Its characteristics are similar to those of copper-phosphorus, except the silver gives this alloy slightly better wetting and flow characteristics. Often it is not necessary to use flux with alloys containing 5% or more silver when joining copper pipe. This is the most common brazing alloy used in air-conditioning and refrigeration work. When sil-phos is used on air-conditioning compressor fittings that are copper-clad steel, care must be taken to make the braze quickly. If the fitting is heated too much or for too long, the copper cladding can be burned off. With this burn-off, the phosphorus can make the steel fitting very brittle, and embrittlement can cause the fitting to crack and leak sometime later.

Silver-Copper

Silver-copper alloys can be used to join almost any metal, ferrous or nonferrous, except aluminum, magnesium, zinc, and a few other low-melting metals. This alloy is often referred to as **silver braze** and is the most versatile. It is among the most expensive alloys, except for the gold alloys.

Nickel

Nickel alloys are used for joining materials that need high strength and corrosion resistance at an elevated temperature. Some applications of these alloys include joining turbine blades in jet engines, torch parts, furnace parts, and nuclear reactor tubing. Nickel will wet and flow acceptably on most metals. When used on copper-based alloys, nickel may diffuse into the copper, stopping its capillary flow.

Nickel and Nickel Alloys A5.14

Nickel and nickel alloys are increasingly used as a substitute for silver-based alloys. Nickel is generally more difficult to use than silver because it has lower wetting and flow characteristics. However, nickel has much higher strength than silver.

Class BNi-1 Class BNi-1 is a high-strength, heat-resistant alloy that is ideal for brazing jet engine parts and for other similar applications.

Class BNi-2 Class BNi-2 is similar to BNi-1 but has a lower melting point and a better flow characteristic.

Class BNi-3 Class BNi-3 has a high flow rate that is excellent for large areas and close-fitted joints.

Class BNi-4 Class BNi-4 has a higher surface tension than the other nickel filler rods, which allows larger fillets and poor-fitted joints to be filled.

Class BNi-5 Class BNi-5 has high oxidation resistance and high strength at elevated temperatures and can be used for nuclear applications.

Class BNi-6 Class BNi-6 is extremely free flowing and has good wetting characteristics. The high corrosion resistance gives this class an advantage when joining low chromium steels in corrosive applications.

Class BNi-7 Class BNi-7 has high resistance to erosion and can be used for thin or honeycomb structures.

Aluminum-Silicon (BAlSi)

Aluminum-silicon brazing filler metals can be used to join most aluminum sheet and cast alloys. The AWS type number 1 flux must be used when brazing aluminum. It is very easy to overheat the joint. If the flux is burned by overheating, it will obstruct wetting. Use standard torch brazing practices but guard against overheating.

Copper and Copper Alloys A5.7

Although pure copper (Cu) can be gas fusion welded successfully using a neutral oxyfuel flame without a flux, most copper filler metals are used to join other metals in a brazing process.

Class BCu-1 Class BCu-1 can be used to join ferrous, nickel, and copper-nickel metals with or without a flux. BCu-1 is also available as a powder that is classified as BCu-1a. This material has the same applications as BCu-1. The AWS type number 3B flux must be used with metals that are prone to rapid oxidation or with heavy oxides such as chromium, titanium, manganese, and others.

Class BCu-2 Class BCu-2 has applications similar to those for BCu-1. However, BCu-2 contains copper oxide suspended in an organic compound. Because copper oxides can cause porosity, tying up the oxides with the organic compounds reduces the porosity.

Silver and Gold

Silver and gold are both used in small quantities when joining metals that will be used under corrosive conditions, when high joint ductility is needed, or when low electrical resistance is important. Because of the ever-increasing price and reduced availability of these precious metals, other filler metals should first be considered. In many cases, other alloys can be used with great success. When substituting a different filler metal for one that has been used successfully, the new metal and joint should first be extensively tested.

JOINT DESIGN

Joint Spacing

The spacing between the parts being joined greatly affects the tensile strength of the finished part. **Table 33-6** lists the spacing requirements at the joining temperature for the most common alloys. As the parts are heated, the initial space may increase or decrease, depending on the

Filler Metal	Joint Spacing	
	in.	mm
BAlSi	0.006–0.025	(0.15–0.61)
BAg	0.002–0.005	(0.05–0.12)
BAu	0.002–0.005	(0.05–0.12)
BCuP	0.001–0.005	(0.03–0.12)
BCuZn	0.002–0.005	(0.05–0.12)
BNi	0.002–0.005	(0.05–0.12)

TABLE 33-6 Brazing Alloy Joint Tolerance

joint design and fixturing. The changes due to expansion can be calculated, but trial and error also works.

The strongest joints are obtained when the parts use lap or scarf joints where the joining area is equal to three-times the thickness of the thinnest joint member, **Figure 33-28**. The strength of a butt joint can be increased if the area being joined can be increased. Parts that are 1/4 in. (6 mm) thick should not be considered for brazing or soldering if another process will work successfully.

Some joints can be designed so that the flux and filler metal may be preplaced. When this is possible, visual checking for filler metal around the outside of the joint is easy. Evidence of filler metal around the outside is a good indication of an acceptable joint.

Joint preparation is also very important to a successful soldered or brazed part. The surface must be cleaned of all oil, dirt, paint, oxides, or any other contaminants. The surface can be mechanically cleaned by using a wire brush or by sanding, sandblasting, grounding, scraping, or filing, or it can be cleaned chemically with an acid, alkaline, or salt bath. Brazing or soldering should start as soon as possible after the parts are cleaned to prevent any additional contamination of the joint.

EXPERIMENT 33-2

Fluxing Action

In this experiment, as part of a small group, you will observe oxide removal by a flux as the flux reaches its effective temperature. For this experiment, you will need a piece of copper, either tubing or sheet, rosin or C flux, and a properly lit and adjusted torch.

Any paint, oil, or dirt must first be removed from the copper. Do not remove the oxide layer unless it is blue-black in color. Put some flux on the copper and start heating it with the torch. When the flux becomes active, the copper that is covered by the flux will suddenly change to a bright coppery color. The copper that is not covered by the flux will become darker and possibly turn blue-black, **Figure 33-29**. Continue heating the copper until the flux is burned off and the once-clean spot quickly builds an oxide layer.

Repeat this experiment, but this time hold the torch farther from the metal's surface. When the flux begins to clean the copper, flash the torch off the metal (quickly move the flame off and back onto the same spot). Try to control the heat so that the flux does not burn off.

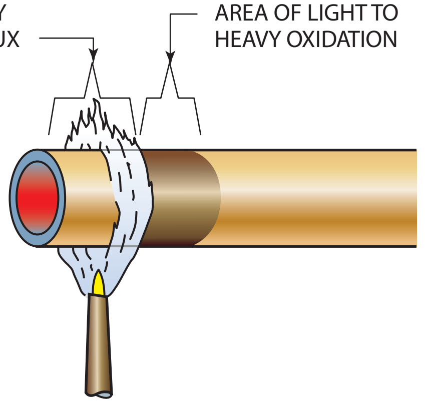

FIGURE 33-29 Copper pipe fluxed and exposed to heat.

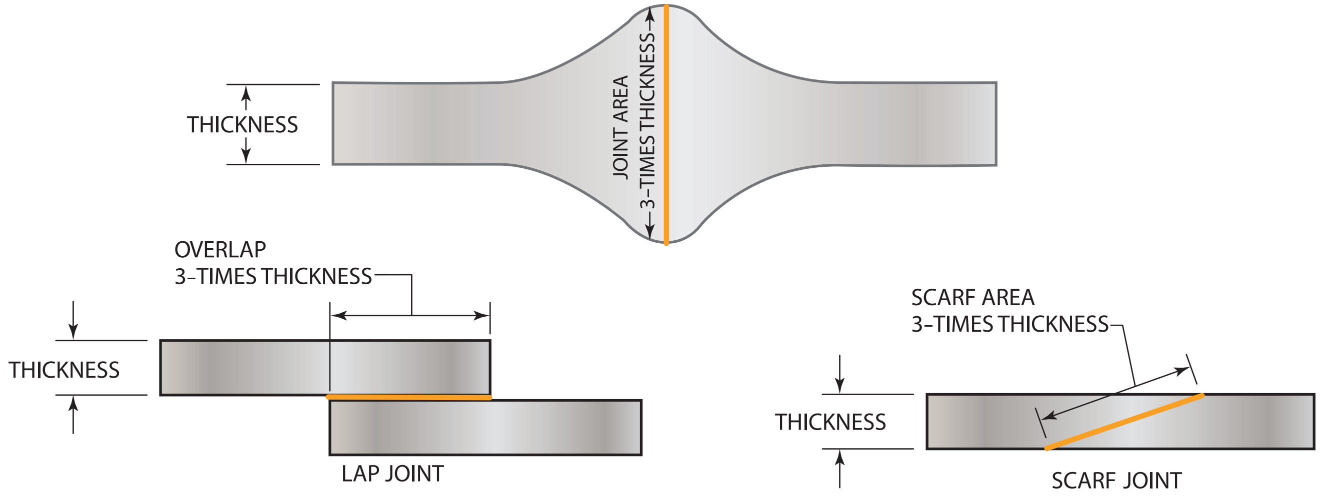

FIGURE 33-28 The joining area should be three-times the thickness of the thinnest joint member.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

EXPERIMENT 33-3

Uniform Heating

In this experiment, as part of a small group, you will learn how to control the flame direction so that two pieces of metal of unequal size are heated at the same rate to the same temperature. For this experiment, you will need two pieces of mild steel, one 16 gauge and the other 1/8 in. (3 mm) thick, and a properly lit and adjusted torch.

Place the two pieces of metal on a firebrick to form a butt joint. Then, take the torch and point the flame toward the thicker piece of metal, moving it as needed so that both plates turn red at the same time. Now move the torch so that the red area is equal in size on both plates. Keep the spot red but do not allow it to melt. Repeat this experiment until you can control the area and rate of heating of both plates at the same time.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

EXPERIMENT 33-4

Tinning or Phase Temperature

In this experiment, as part of a small group, you will observe the wetting of a piece of metal by a filler metal. For this experiment, you will need one piece of 16-gauge mild steel, BRCuZn filler metal rod, powdered flux, and a properly lit and adjusted torch.

Place the sheet flat on a firebrick. Heat the end of the rod and dip it in the flux so that some flux sticks on the rod, **Figure 33-30A**, **B**, and **C**. BRCuZn brazing rods are available as both bare rods and prefluxed, **Figure 33-30D**. Direct the flame onto the plate. When the sheet gets hot, hold the brazing rod in contact with the sheet, directing the flame so that a large area of the sheet is dull red and the rod starts to melt, **Figure 33-31**. After a molten pool of braze metal is deposited on the sheet, remove the rod and continue heating the sheet

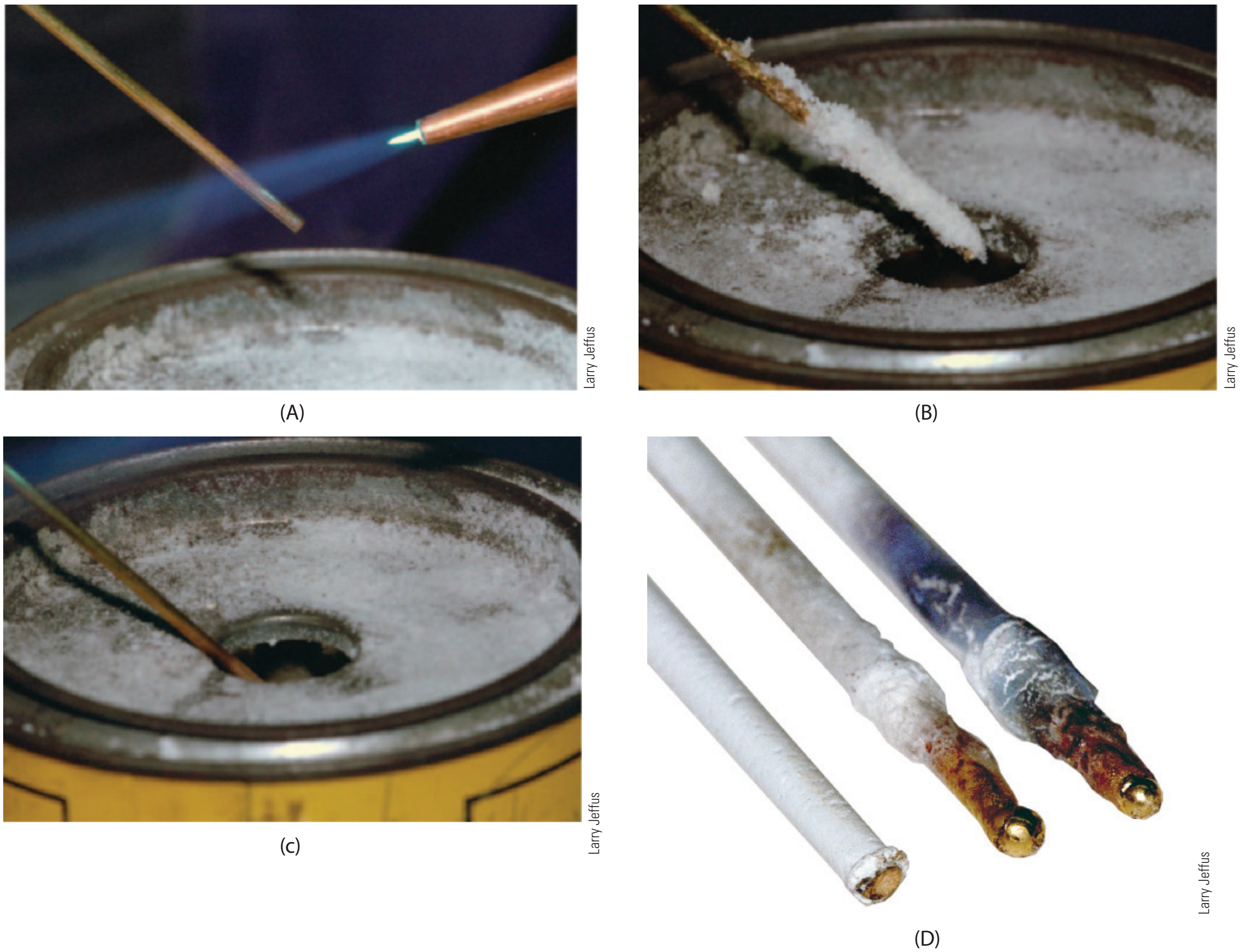

FIGURE 33-30 (A) Heating a brazing rod. (B) Dipping the heated rod into the flux. (C) Flux stuck to rod ready for brazing. (D) Prefluxed brazing rods.

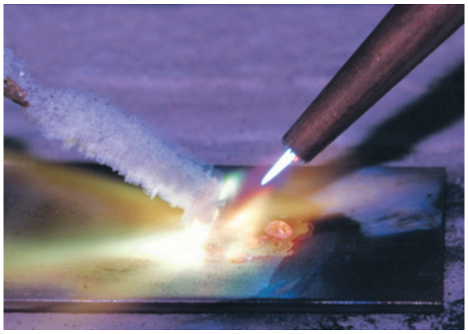

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FIGURE 33-31 Deposit a spot of braze on the plate and continue heating the plate until the braze flows onto the surface.

and molten pool until the braze metal flows out. Repeat this experiment until you can get the braze metal to flow out in all directions equally at the same time.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

BRAZING PRACTICES

The brazing practices that follow use copper-zinc alloys (BRCuZn) for brazing joints on mild steel. Using prefluxed rods is easier for students than using powdered flux, which has to have the hot tip of the brazing rod dipped to apply. Because you may be asked to braze with bare brazing rods, the practices explain how to use them. If you are using prefluxed rods, just ignore this step.

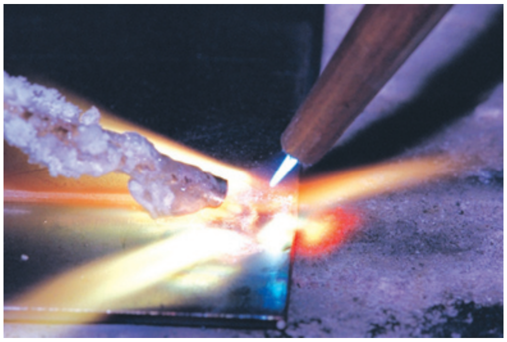
PRACTICE 33-1

Brazed Stringer Bead

Using a properly lit and adjusted torch, 6 in. (152 mm) of clean 16-gauge mild steel, brazing flux, and BRCuZn brazing rod, you will make a straight bead the length of the sheet.

Place the sheet flat on a firebrick and hold the flame at one end until the metal reaches the proper temperature. Then, touch the flux-covered rod to the sheet and allow a small amount of brazing rod to melt onto the hot sheet, **Figure 33-32**. Once the molten brazing metal wets the sheet, start moving the torch in a circular pattern while dipping the rod into the molten braze pool as you move along the sheet. If the size of the molten pool increases, you can control it by reducing the torch angle, raising the torch, traveling at a faster rate, or flashing the flame off the molten braze pool, **Figure 33-33A**, **B**, and **C**. Flashing the torch off a braze joint will not cause oxidation problems as it does when welding because the molten metal is protected by a layer of flux.

As the braze bead progresses across the sheet, dip the end of the rod back in the flux, if a powdered flux is used, as often as needed to keep a small molten pool of flux ahead of the bead, **Figure 33-34**.



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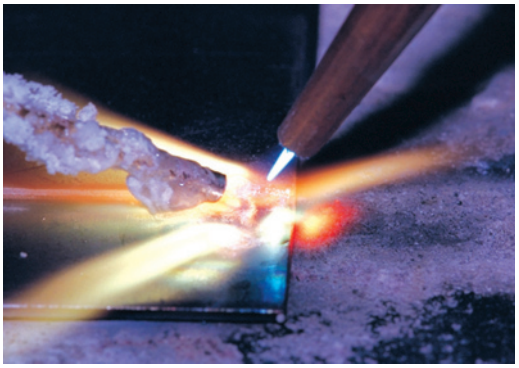
(A)



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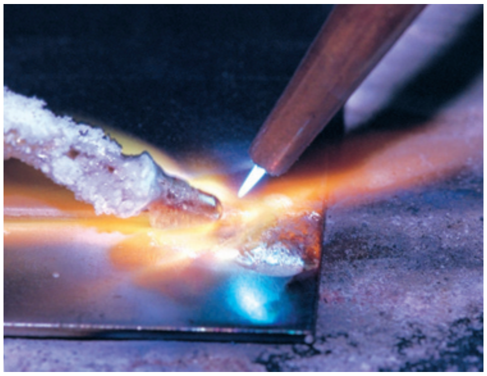

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(C)

FIGURE 33-33 (A) Once the plate is up to temperature, start adding more filler. (B) Dip the brazing rod into the leading edge of the molten weld pool. (C) Remove the rod from the flame area when it is not being added to the molten weld pool.

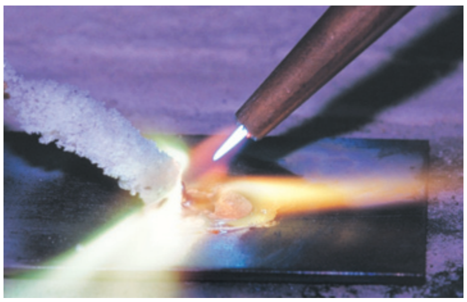

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FIGURE 33-32 Checking the surface temperature with a spot of braze metal.

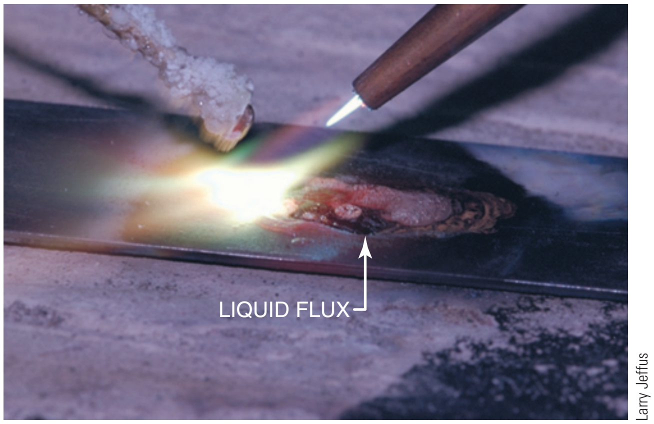

FIGURE 33-34 Observe the molten flux flowing ahead of the molten weld pool.

The object of this practice is to learn how to control the size and direction of the braze bead. Controlling the width, buildup, and shape shows that you have a good understanding and control of the process. Keeping the braze bead in a straight line indicates that you have mastered the technique well enough to watch the bead and the direction at the same time. Turn off the cylinders, bleed the hoses, back out the regulator adjusting screws, and clean your work area when you are finished.

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PRACTICE 33-2

Brazed Butt Joint

Using the same equipment and setup as listed in Practice 33-1, make a braze butt joint on two pieces of 16-gauge mild steel sheet that is 6 in. (152 mm) long.

Place the metal flat on a firebrick, hold the plates tightly together, and make a tack braze at both ends of the joint. If the plates become distorted, they can be bent back into shape with a hammer before making another tack weld in the center. Align the sheets so that you can comfortably make a braze bead along the joint. Starting as you did in Practice 33-1, make a uniform braze along the joint. Repeat this practice until a uniform braze can be made without defects. Turn off the cylinders, bleed the hoses, back out the regulator adjusting screws, and clean your work area when you are finished.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 33-3

Brazed Butt Joint with 100% Penetration

Using the same equipment, material, and setup as described in Practice 33-2, make a brazed butt joint with 100% penetration, **Figure 33-35**. To ensure that 100% penetration is obtained, a little additional heat is required to flow the braze metal through the joint. Apply the additional heat just ahead

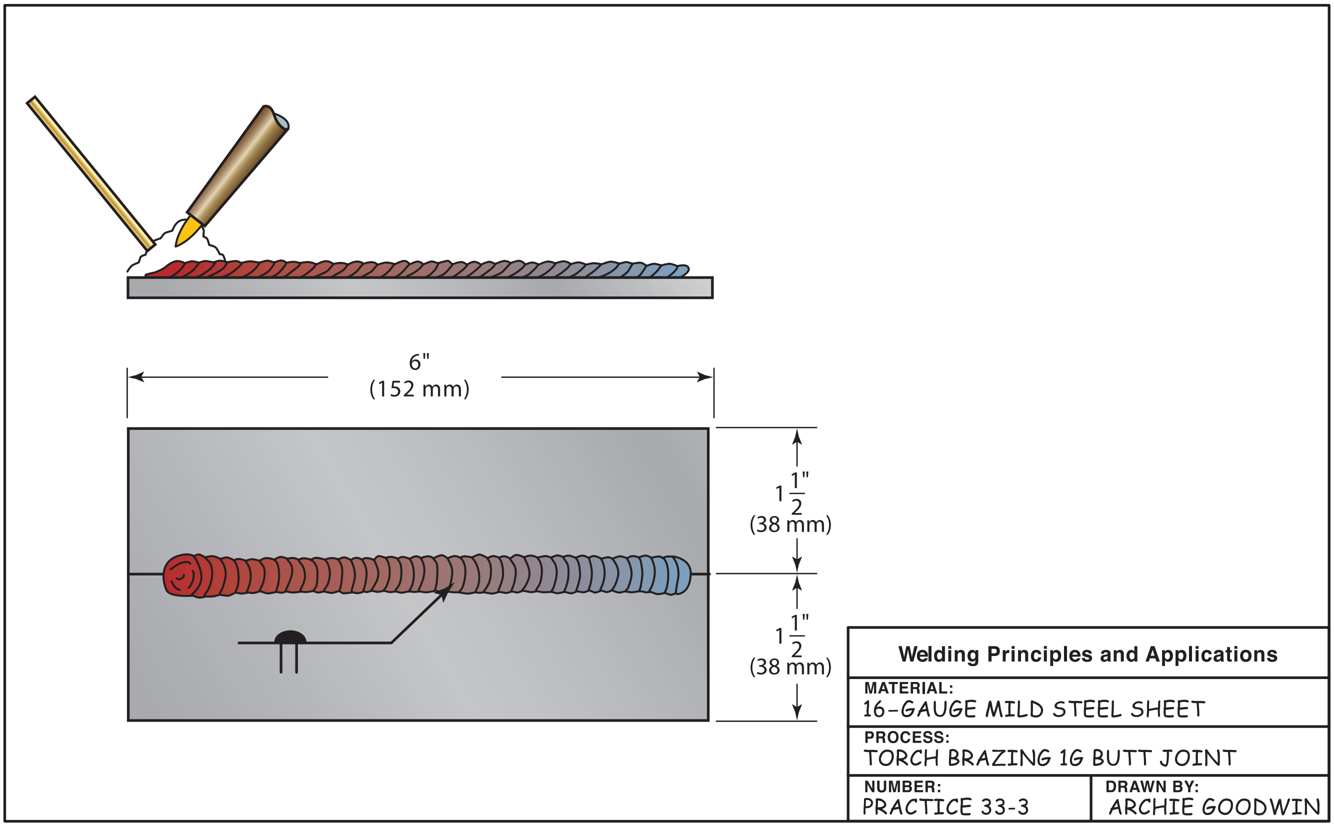

FIGURE 33-35 Brazed butt joint with 100% penetration.

of the bead on the base sheets. After the braze is completed, turn the plate over and look for a small amount of braze showing along the entire joint. Repeat this practice until the joint can be made without defects. Turn off the cylinders, bleed the hoses, back out the regulator adjusting screws, and clean your work area when you are finished.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 33-4

Brazed Tee Joint

Using the same equipment, material, and setup as listed in Practice 33-2, you will make a brazed tee joint with 100% root penetration, **Figure 33-36**.

Tack the pieces of metal into a tee joint as you did in Practice 33-2. To obtain 100% penetration, direct the flame on the sheets just ahead of the braze bead, being careful not to overheat the braze metal. If the bead has a notch, the root of the joint is still not hot enough to allow the braze metal to flow properly. If the braze metal appears to have flowed properly after you have completed the joint, look at the back of the joint for a line of braze metal that flowed through. Repeat this practice until the joint can be made without defects. Turn off the cylinders, bleed the hoses, back out the regulator adjusting screws, and clean your work area when you are finished.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 33-5

Brazed Lap Joint

Using the same equipment, material, and setup as listed in Practice 33-2, you will make a brazed lap joint in the flat position.

Place the pieces of sheet metal on a firebrick so that they overlap each other by approximately 1/2 in. (13 mm). It is important that the pieces be held flat relative to each other, **Figure 33-37**. Make a small tack braze on both ends and then one or two tack brazes along the joint. Hold the torch so the flame moves along the

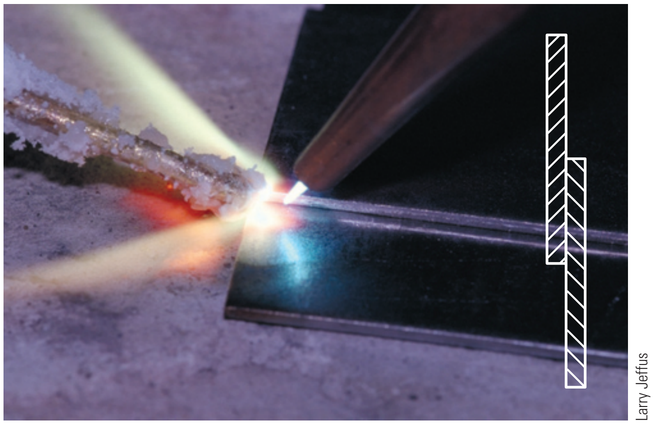

FIGURE 33-37 Tack braze lap joint.

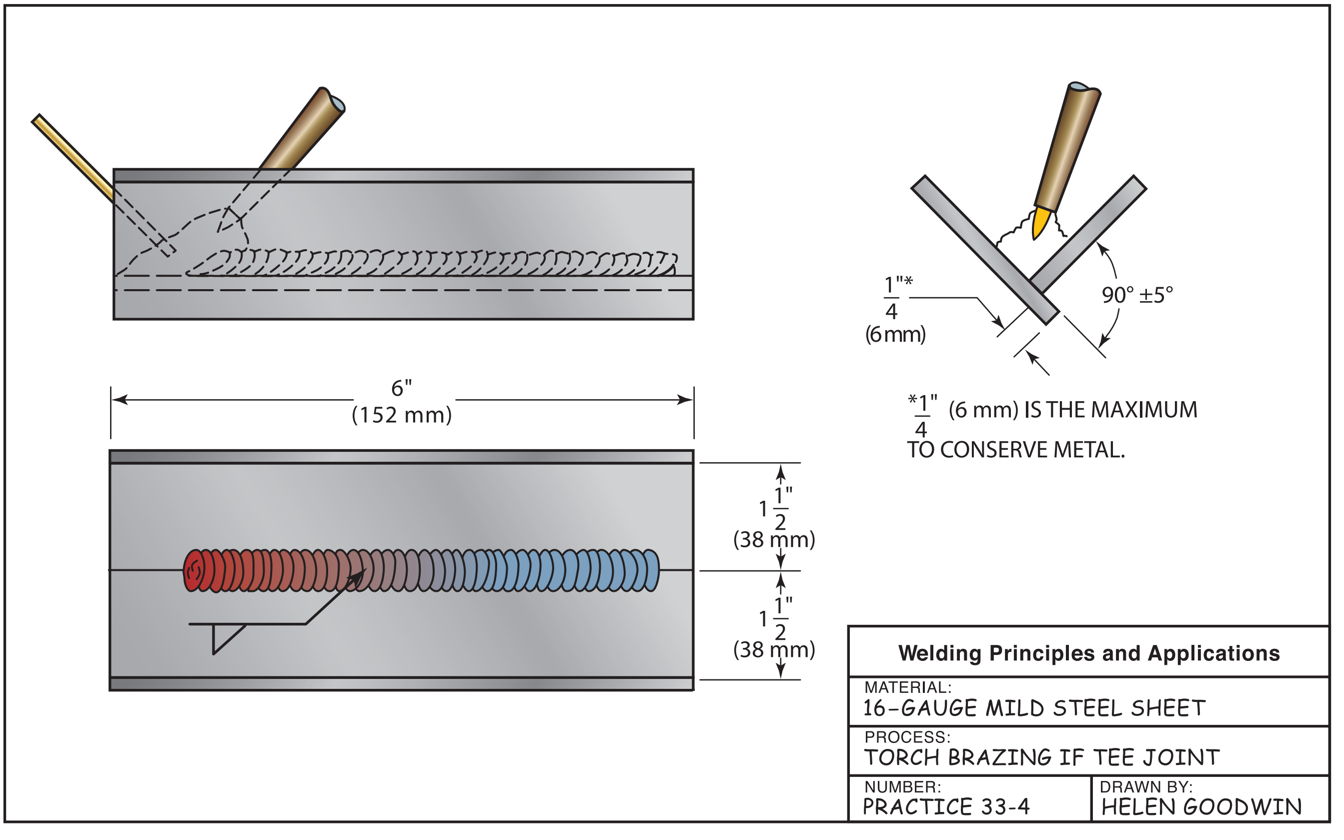

FIGURE 33-36 Brazed tee joint.

joint and heats up both pieces at the same time. When the sheets are hot, touch the rod to the sheets and make a bead similar to the butt joint. After completing the brazed joint, it should be uniform in width and appearance. Repeat this practice until the joint can be made without defects. Turn off the cylinders, bleed the hoses, back out the regulator adjusting screws, and clean your work area when you are finished.

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PRACTICE 33-6

Brazed Lap Joint with 100% Penetration

Using the same equipment, material, and setup as listed in Practice 33-2, you will make a lap joint with 100% penetration in the flat position, **Figure 33-38**.

Tack the plates together and start the bead the same way as you did in Practice 33-5. Next, move the torch back onto the top plate, as you did for Practice 33-5, so that the braze metal will be drawn into the joint. After the joint is completed, check the back side of the joint for braze metal showing along the joint. Repeat this practice until the joint can be made without defects. Turn off the cylinders, bleed the hoses, back out the regulator adjusting screws, and clean your work area when you are finished.

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PRACTICE 33-7

Brazed Tee Joint, Thin to Thick Metal

Using a properly lit and adjusted torch, two pieces of mild steel 6 in. (152 mm) long, one 16 gauge and the other 1/4 in. (6 mm) thick, brazing flux, and BRCuZn brazing rod, you will make a tee joint in the flat position.

Hold the 16-gauge metal vertically on the 1/4-in. (6-mm) plate and tack braze both ends. The vertical member of a tee joint heats faster than the flat member because the heat on the vertical member can be conducted in only one direction, **Figure 33-39**. The thin plate will heat faster than the thick plate because there is less mass (metal). For the braze bead to be equal, both plates must be heated equally. Direct the flame on the thicker plate, as shown

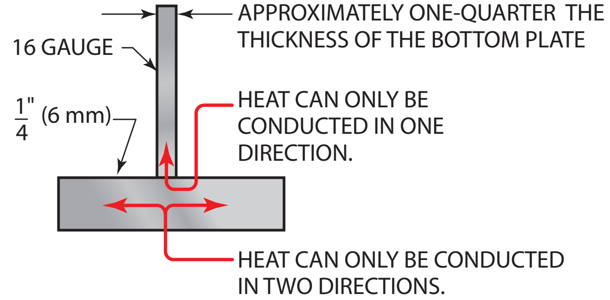

FIGURE 33-39 Unequal rate of heating due to a difference in mass.

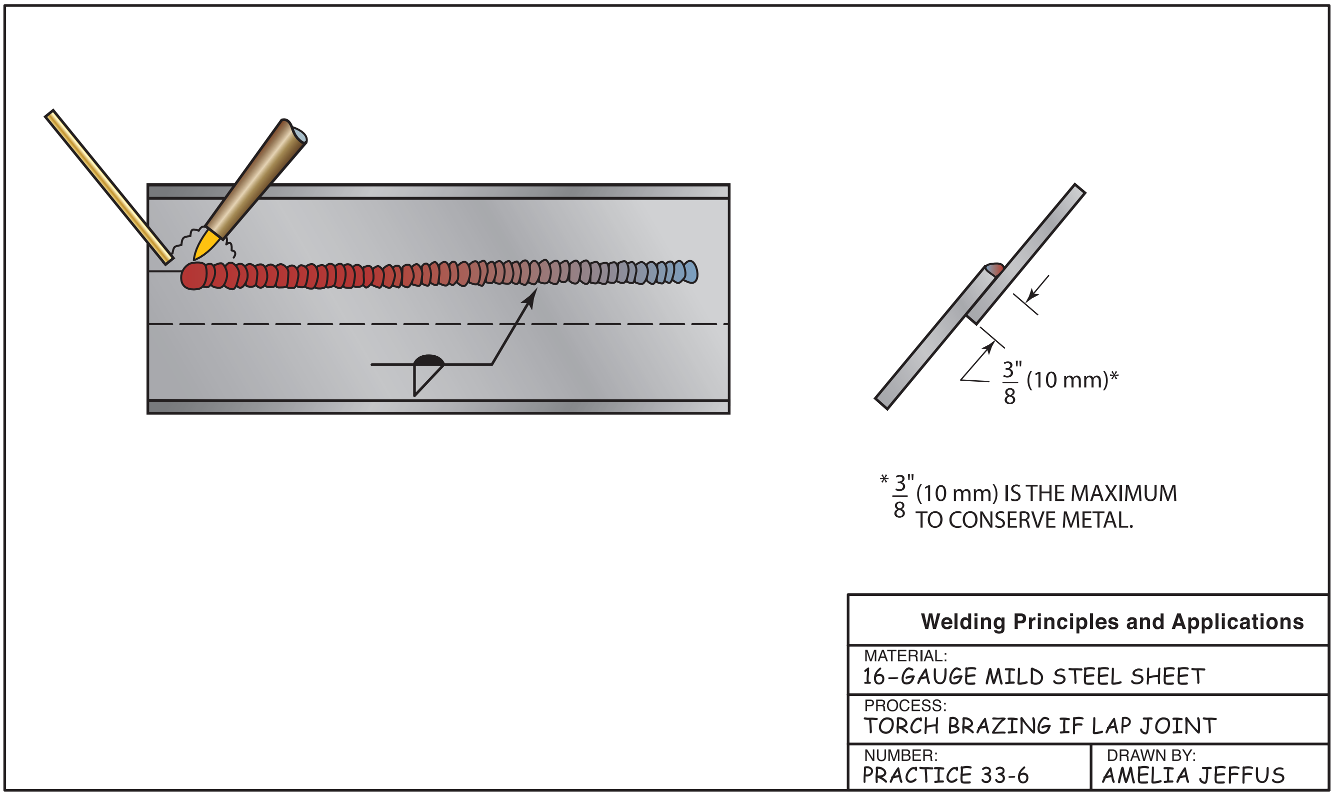

FIGURE 33-38 Horizontal lap joint.

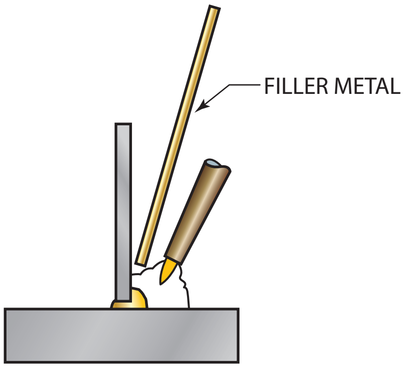

FIGURE 33-40 Torch and rod positions to balance heating between parts of unequal thickness.

in **Figure 33-40**, and add the brazing rod on the thinner plate. This action will keep the thin plate from overheating. Make a braze along the joint that is uniform in appearance. Repeat this practice until the joint can be made without defects. Turn off the cylinders, bleed the hoses, back out the regulator adjusting screws, and clean your work area when you are finished.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 33-8

Brazed Lap Joint, Thin to Thick Metal

Using the same equipment, materials, and setup as described in Practice 33-7, make a lap joint in the horizontal position, **Figure 33-41**.

Tack braze the pieces together, making sure that they are held tightly together. Place the metal on a firebrick with the thin metal up. Apply heat to the exposed thick metal and more slowly to the overlapping thin metal so that conduction from the thin metal will heat the thick metal at the lap, **Figure 33-42**. If the braze is started before the thick metal is sufficiently heated, the filler metal will be chilled, and a bond will not occur. After the joint is completed and cooled, tap the joint with a hammer to see if there is a good bonded joint. **Figure 33-43** shows a broken braze joint that bonded properly only in certain areas. Repeat this practice until the joint can be made without defects. Turn off the cylinders, bleed the hoses, back out the regulator adjusting screws, and clean your work area when you are finished.

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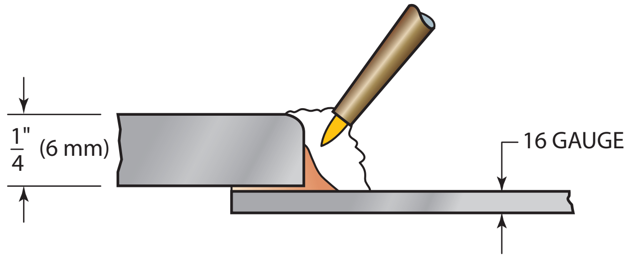

FIGURE 33-42 Direct the heat on the thicker section to ensure proper bonding.

PRACTICE 33-9

Braze Welded Butt Joint, Thick Metal

Using a properly lit and adjusted torch, two pieces of mild steel plate 6 in. (152 mm) long, one 1/4 in. (6 mm) thick, one 16-gauge flux, and BRCuZn filler metal, you will make a flat braze welded butt joint.

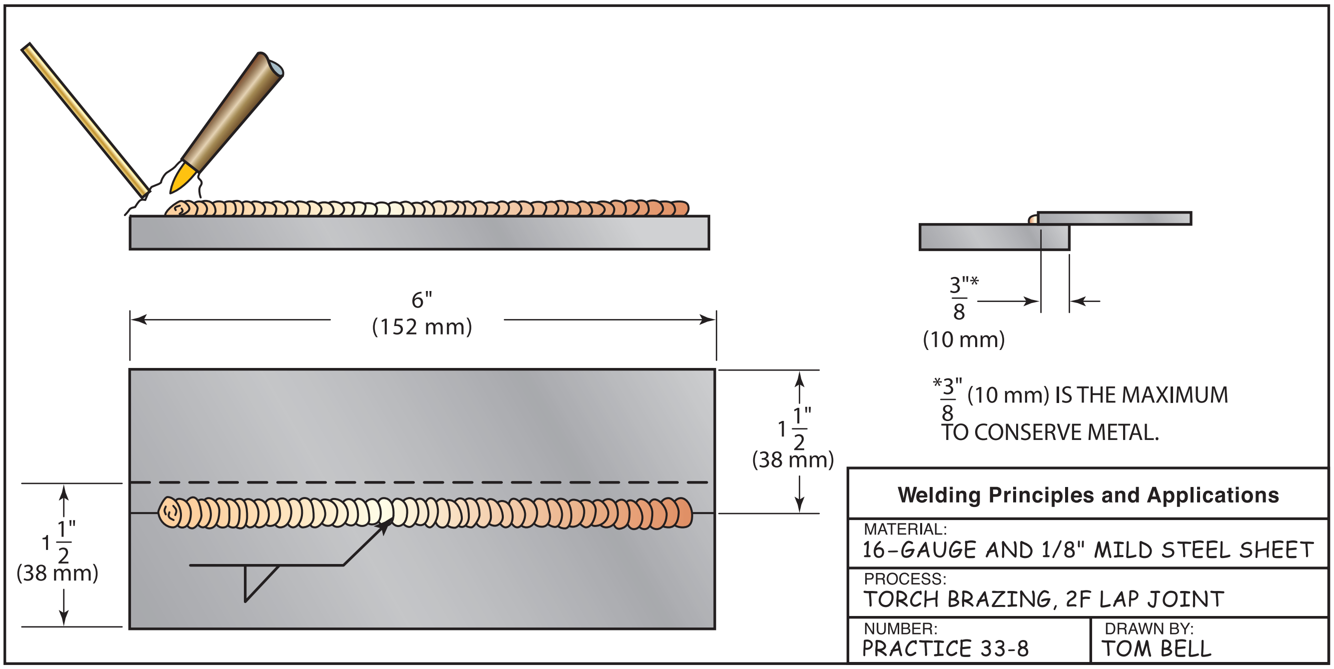

FIGURE 33-41 Brazed lap joint, thin to thick metal.

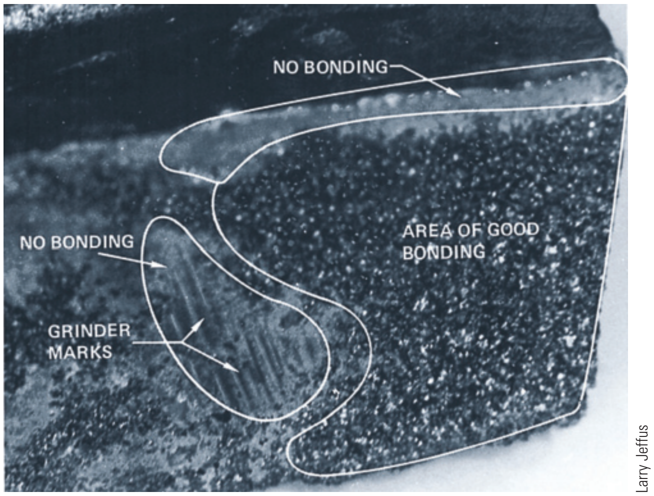

FIGURE 33-43 Only part of this braze joint is bonded properly. Grinder marks can be seen casted into the braze. The base metal was too cool for proper bonding to occur.

Grind the edges of the 1/4-in. (6-mm) plate so that they are slightly rounded, **Figure 33-44**. The rounded edges are better when used for brazing because they distribute the strain on the braze more uniformly. After the plates have been prepared, tack braze both ends together. Because of the mass of the plates, it may be necessary to preheat the plates. This helps the penetration and eliminates cold lap at the root. The flame should be moved in a triangular motion so that the root is heated, as well as the top of the bead, **Figure 33-45**. When the joint is complete and cool, bend the joint to check for complete root bonding, **Figure 33-46**. Repeat this practice until the joint can be made without defects. Turn off the cylinders, bleed the hoses, back out the regulator adjusting screws, and clean your work area when you are finished.

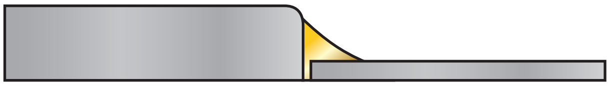

FIGURE 33-44 Joint preparation.

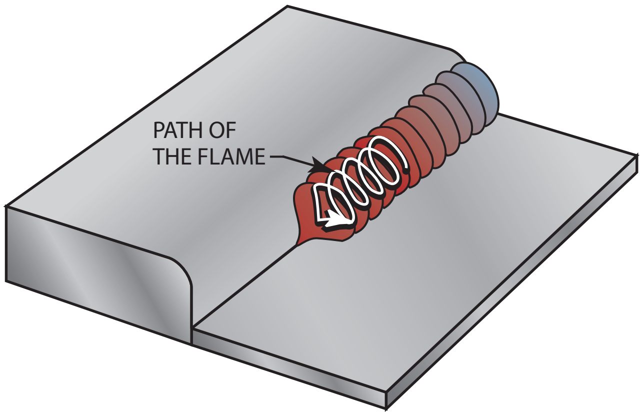

FIGURE 33-45 Flame movement to ensure 100% root penetration.

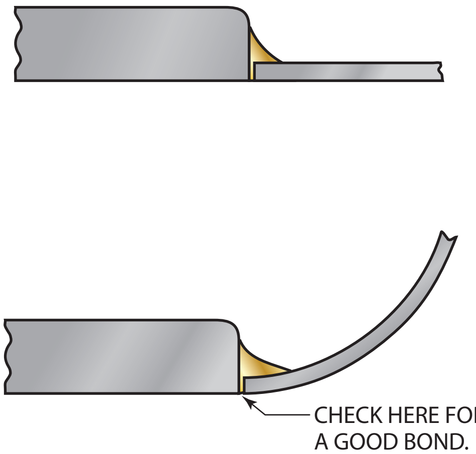

FIGURE 33-46 Bend the braze joint to check for a good bond.

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PRACTICE 33-10

Braze Welded Tee Joint, Thick Metal

Using the same equipment, materials, and setup as listed in Practice 33-9, you will make a braze welded tee joint in the flat position.

As with the butt joint, the edge of the plate is to be slightly rounded, and the metal may have to be preheated to get a good bond at the root. Direct the flame toward the bottom plate and into the root and add the filler metal back into the root. Watch for a notch, which indicates lack of bonding at the root. When the braze is complete and cool, bend it with a hammer to check for a bond at the root, **Figure 33-47**. Repeat this practice until the joint can be made without defects. Turn off the cylinders, bleed the hoses, back out the regulator adjusting screws, and clean your work area when you are finished.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

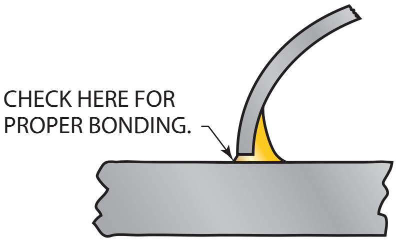

FIGURE 33-47 Bend test to check for root bonding.

SURFACE BUILDUP AND HOLE FILL PRACTICES

Surfaces on worn parts are often built up again with braze metal. Braze metal is ideal for parts that receive limited abrasive wear because the buildup is easily machinable. Unlike welding or hardsurfacing, **braze buildup** has no hard spots that make remachining difficult. Braze buildups are good both for flat and round stock. The lower temperature used in brazing does not tend to harden or soften the base metal as much as in welding.

Holes in light-gauge metal can be filled using braze metal. The filled hole can be ground flush if it is required for clearance, leaving a strong patch with minimum distortion.

PRACTICE 33-11

Braze Welding to Fill a Hole

Using a properly lit and adjusted torch, one piece of 16-gauge mild steel, flux, and BRCuZn filler rod, you will fill a 1-in. (25-mm) hole. Place the piece of metal on two firebricks so that the hole is between them. Start by running a stringer bead around the hole, **Figure 33-48**. Once the bead is complete, turn the torch at a very sharp angle and point it at the edge of the hole nearest the torch. Hold the end of the filler rod in the flame so that both the bead around the hole and the rod meet at the same time, **Figure 33-49**. Put the rod in the molten bead and flash the torch off to allow the molten braze pool to cool. When it has cooled, repeat this process. Surface tension will hold a small piece of molten metal in place. If the piece of molten metal becomes too large, it will drop through. Progress around the hole as many times as needed to fill the hole. When the braze weld is complete, it should be fairly flat with the surrounding metal. Repeat this practice until it can be made without defects. Turn off the cylinders, bleed the hoses, back out the regulator adjusting screws, and clean your work area when you are finished.

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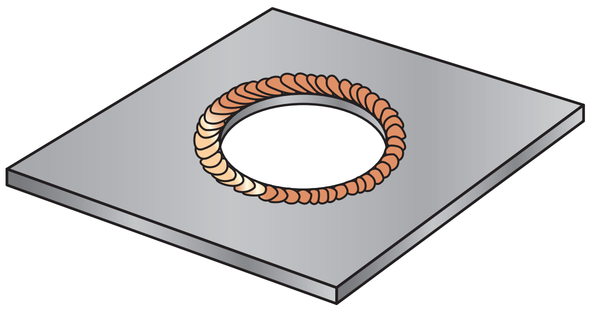


FIGURE 33-48 Filling a hole with braze. First run a bead around the outside of the hole.

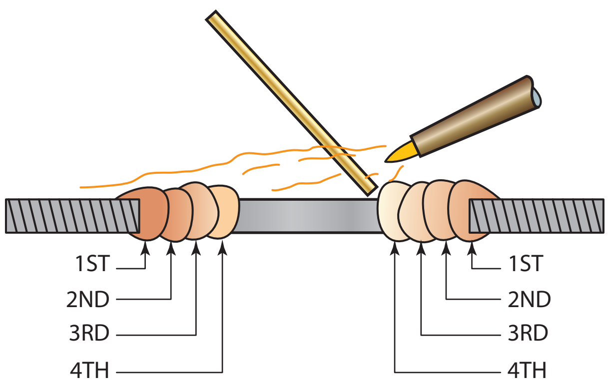


FIGURE 33-49 Keep running beads around the hole until it is closed.

PRACTICE 33-12

Flat Surface Buildup

Using a properly lit and adjusted torch, a 3-in. (76-mm) square of 1/4-in. (6-mm) mild steel, flux, and BRCuZn filler rod, you will build up a surface.

Place the square plate flat on a firebrick. Start along one side of the plate and make a braze weld down that side. When you get to the end, turn the plate 180° and braze back alongside the first braze, **Figure 33-50**, covering approximately one-half of the first braze bead. Repeat this procedure until the side is covered with braze metal.

Turn the plate 90° and repeat the process, **Figure 33-51**. Be sure that you are getting good fusion with the first layer and that there are no slag deposits trapped under the braze. Be sure to build up the edges so that they can be cut back square. This process should be repeated until there is at least 1/4 in. (6 mm) of buildup on the surface. The surfacing can be checked visually or by machining the square to a 3-in. (76-mm) × 1/2-in. (13-mm) block and checking for slag inclusions. The plate will warp as a result of this buildup. If the plate is going to be used, then it should be clamped down to prevent distortion. Turn off the cylinders, bleed the hoses, back out the regulator adjusting screws, and clean your work area when you are finished.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 33-13

Round Surface Buildup

Using a properly lit and adjusted torch, one piece of mild steel bolt 1/2 in. (13 mm) in diameter × 3 in. (76 mm) long, flux, and BRCuZn brazing rod, you will build up a round surface.

In the flat position, start at one end and make a braze weld bead, 1 1/2 in. (38 mm) long, along the side of the steel bolt. Turn the bolt and make another bead next to the first bead, covering approximately one-half of the first, **Figure 33-52** and **Figure 33-53**. Repeat this procedure until the bolt is 1 in. (25 mm) in diameter. It may be necessary

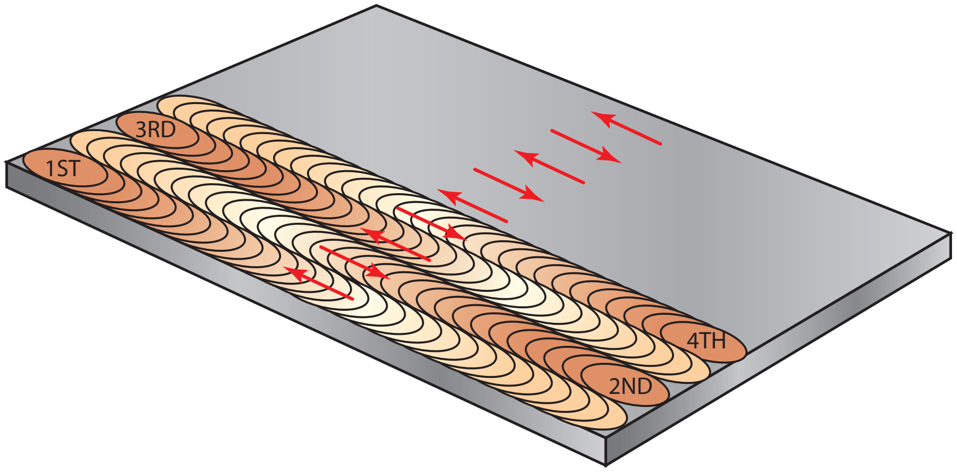


FIGURE 33-50 Braze buildup, first layer.

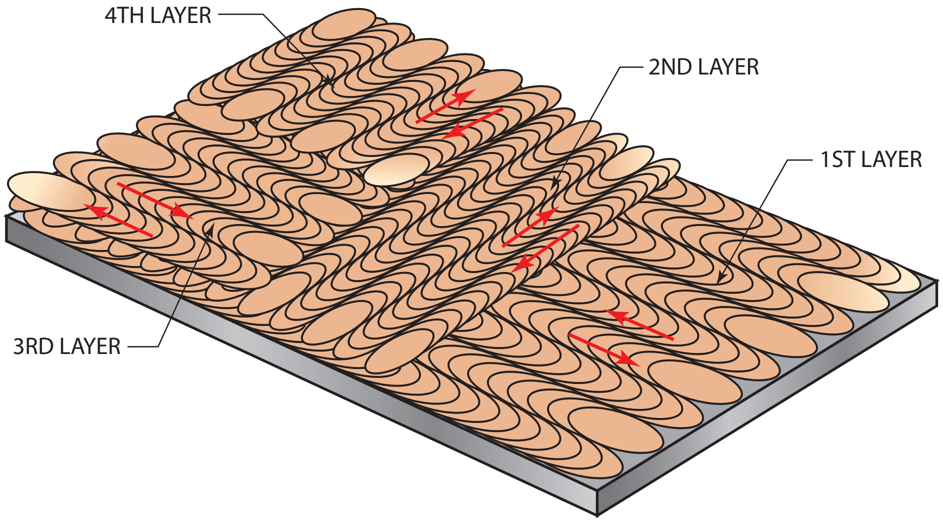


FIGURE 33-51 When building up a surface, alternate the direction of each layer.

FIGURE 33-52 Round shaft built up with braze.

FIGURE 33-53 Shaft turned down to check for slag inclusions or poor bonding.

to make a braze bead around both ends of the buildup to keep it square. The buildup can be visually inspected, or it can be turned down in a lathe. Repeat this practice until it can be made without defects. Turn off the cylinders, bleed the hoses, back out the regulator adjusting screws, and clean your work area when you are finished.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

SILVER BRAZING PRACTICES

The silver brazing practices that follow will use BCuP-2 to BCuP-5 alloys to make brazed copper pipe joints. The melting temperature for the alloys is approximately 1400°F (760°C). At these temperatures the copper pipe will be glowing a dull red. The best types of flame to use for this type of brazing are air acetylene, air MAPP®, air propane, or any air fuel-gas mixture. The most popular types are air acetylene and air MAPP®. If an oxyacetylene torch is used,

it is easy to overheat the alloy. To prevent overheating with an oxyacetylene flame, keep the torch moving and hold the flame so that the inner cone is approximately 1 in. (25 mm) from the surface.

When using BCuP silver brazing alloys on clean copper, it is not necessary to use a flux. The phosphorus in these alloys makes them self-fluxing. It is the phosphorus that promotes the wetting and enhances the flow of the alloy into the joint space.

PRACTICE 33-14

Silver Brazing Copper Pipe, 2G Vertical Down Position

You will make a silver brazed joint in copper pipe in the 2G vertical down position, **Figure 33-54**, using the following: a properly lit and adjusted torch with air acetylene, air MAPP®, air propane, or any air fuel-gas mixture; two or more pieces of 1/2-in. to 1-in. (13-mm to 25-mm) copper pipe with matching copper pipe fittings; BCuP-2 to BCuP-5 brazing metal; steel wool, sand cloth, and/or wire brush; safety glasses with side shields; gloves; proper protective clothing; pliers; and any other required personal safety equipment.

1. Set the regulator pressures according to the manufacturer's specifications for your fuel type and tip size.
2. Clean the pipe and fitting using the steel wool, sand cloth, or a wire brush. *Note:* Do not touch the cleaned surfaces with your hands. Oils from your skin can prevent the braze metal from wetting. This can result in leaks.
3. Slide the fitting onto the pipe. Be sure that the pipe is completely seated at the bottom of the fitting.
4. Heat the brazing rod and make a bend in the wire approximately 3/4 in. (19 mm) from the end. This will give you a gauge so that you do not put too much brazing metal in the joint.
5. Heat the pipe first, but not too much. *Note:* As the pipe is heated it will expand, forming a tighter fit in the fitting. This will aid in conducting heat deeper into the fitting socket, and the tighter fit will aid in capillary attraction of the braze metal.
6. Once the pipe is hot, but not glowing red, start heating the fitting. Keep the torch moving to uniformly heat the entire joint.
7. The joint is at the correct temperature for brazing when the braze metal starts to wet the surface. Touch the tip of the brazing rod to check the parts so that you know when they reach the correct temperature.
8. Move the flame to the back side of the joint and feed the brazing rod into the joint space. *Note:* A slight pressure directly into the joint with the brazing rod will help it flow deeper into the fitting. This is especially helpful on larger-diameter pipes.
9. Next, move the torch and brazing rod around the pipe and fitting so that the entire joint will be filled. There should be a slight fillet showing all the way around the joint, **Figure 33-55**. *Note:* The braze metal fillet adds very little strength to the joint, but it is an easy way to make sure that the joint is leak-free.

After the pipe has cooled, test the joint by sawing the fitting into a point just past the end of the inside pipe, **Figure 33-56**. Place the pipe vertically in a vise and saw it into quarters, **Figure 33-57**. Use a hammer and flat surface to flatten out each quarter section, **Figure 33-58**.

With the joint prepared, check for complete penetration of the braze alloy, **Figure 33-59**. Check the sides of the flattened quarters for braze alloy, **Figure 33-60**, or other defects.

Repeat this practice until you can make defect-free joints. Turn off the cylinder, bleed the hoses, back out the regulator adjusting screws, and clean your work area when you are finished.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

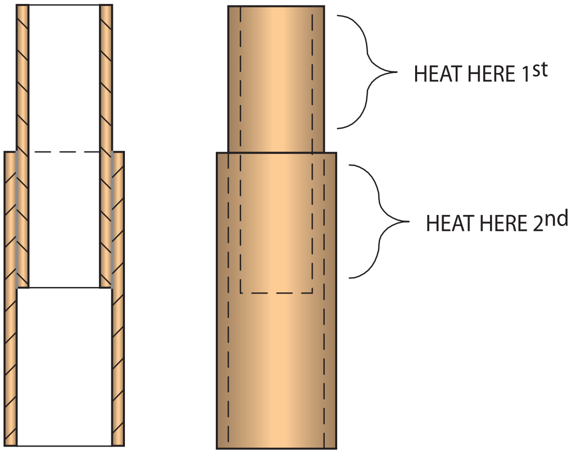


FIGURE 33-54 2G vertical down position.

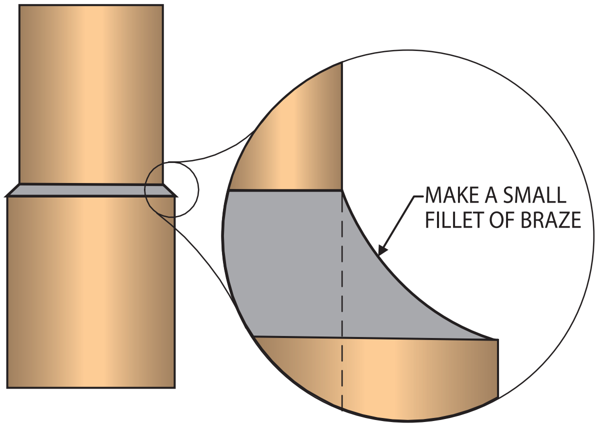


FIGURE 33-55 Making a smooth brazed fillet is a good way to prevent pin hole leaks.

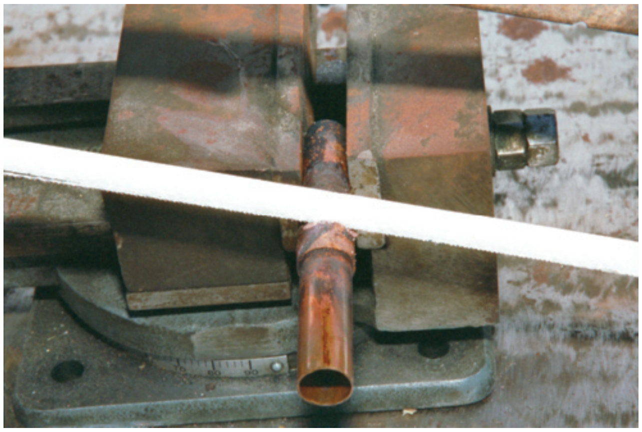


FIGURE 33-56 Saw the joint in two.

FIGURE 33-59 Complete joint fill.

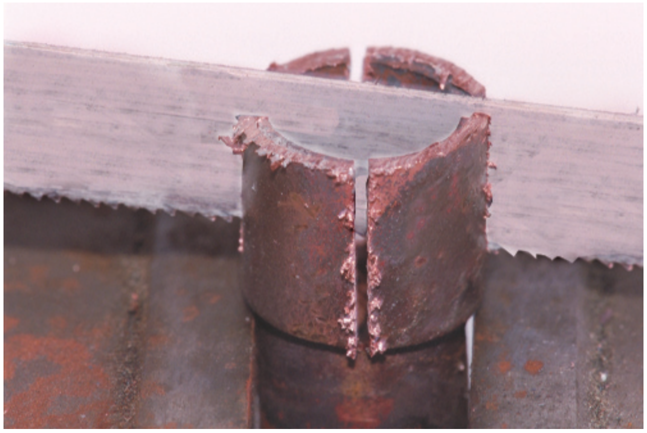


FIGURE 33-57 Quarter saw the joint.

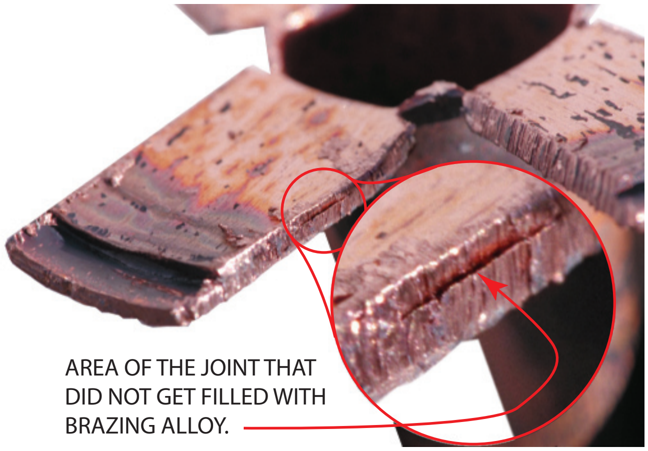


FIGURE 33-60 Incomplete joint fill.

FIGURE 33-58 Flatten the sawed quarters.

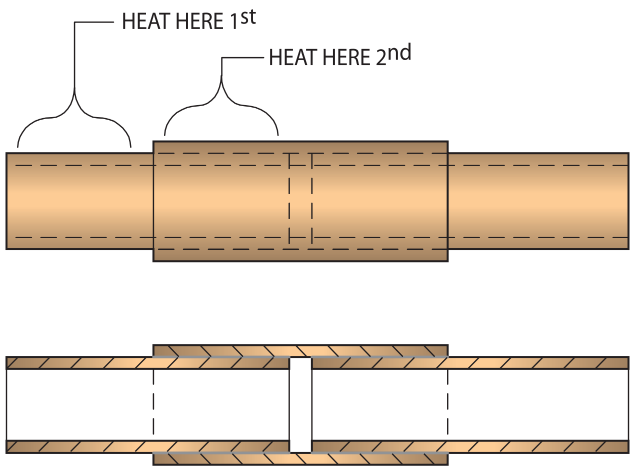


FIGURE 33-61 5G horizontal fixed position.

PRACTICE 33-15

Silver Brazing Copper Pipe, 5G Horizontal Fixed Position

Using the same equipment, materials, setup, and procedures as described in Practice 33-14, make a silver brazing copper pipe joint in the 5G horizontal fixed position.

1. Mount the pipe in a horizontal position, **Figure 33-61**.
2. Start by heating entirely around the pipe. Move the flame back and forth around the entire diameter of the pipe. *Note:* On pipe that is larger than 1 in. (25 mm), concentrate most of your heating on the top of the pipe because the flame may not have enough heat to heat the entire pipe to the brazing temperature.

3. Once the pipe is hot but not glowing red, start heating the fitting. Keep the torch moving to heat the entire joint uniformly.
4. The joint is at the correct temperature for brazing when the braze metal starts to wet the surface. Touch the tip of the brazing rod to check the parts so that you know when they reach the correct temperature.
5. Move the flame to the back side of the joint and feed the brazing rod into the joint space with a slight pressure.
6. Gravity and capillary action will pull the braze metal down to the bottom of the joint if the entire diameter of the pipe is at the correct temperature. If necessary, move the torch slowly down the sides of the pipe to bring this part of the joint up to the brazing temperature. Add braze metal as needed, but do not overfill the joint. An indication that the joint has been overfilled is a bump of braze metal hanging from the bottom of the finished joint.

Repeat this practice until you can make defect-free joints. Turn off the cylinder, bleed the hoses, back out the regulator adjusting screws, and clean your work area when you are finished.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 33-16

Silver Brazing Copper Pipe, 2G Vertical Up Position

Using the same equipment, materials, setup, and procedures as described in Practice 33-14, make a silver brazing copper pipe joint in the 2G vertical up position.

1. Mount the pipe in a vertical up position, **Figure 33-62**.
2. Start by heating entirely around the pipe. Move the flame back and forth around the entire diameter of the pipe.

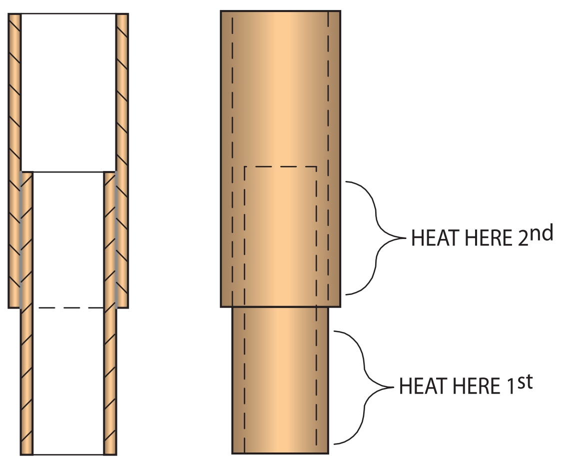


FIGURE 33-62 2G vertical up position.

3. Once the pipe is hot, but not glowing red, move the flame up onto the fitting to start it heating. Keep the torch moving to uniformly heat the entire joint.
4. The joint is at the correct temperature for brazing when the braze metal starts to wet the surface. Touch the tip of the brazing rod to check the parts so that you know when they reach the correct temperature.
5. Move the flame to the top of the joint and feed the brazing rod into the joint space with a slight pressure.
6. The heat and capillary action will pull the braze metal up into the top of the joint space if the pipe is at the correct temperature. Add braze metal as needed, but do not overfill the joint. An indication that the joint has been overfilled is drips of braze metal running down the vertical pipe below the joint.

Repeat this practice until you can make defect-free joints. Turn off the cylinder, bleed the hoses, back out the regulator adjusting screws, and clean your work area when you are finished.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

SOLDERING PRACTICES

The soldering practices that follow use tin-lead or tin-antimony solders. Both solders have a low melting temperature. If an oxyacetylene torch is used, it is very easy to overheat the solder. Caution is necessary because most of the fluxes used with this type of solder are easily overheated. The best type of flame to use for this type of soldering is air acetylene, air MAPP®, air propane, or any air fuel-gas mixture. The most popular types are air acetylene and air propane. If galvanized metal is used, then additional ventilation should be used to prevent zinc oxide poisoning.

PRACTICE 33-17

Soldered Tee Joint

Using a properly lit and adjusted torch, two pieces of 18-gauge to 24-gauge mild steel sheet 6 in. (152 mm) long, flux, and tin-lead or tin-antimony solder wire, you will solder a flat tee joint.

Hold one piece of metal vertical on the other piece and spot solder both ends. If flux cored wire is not being used, paint the flux on the joint at this time. Hold the torch flame so it moves down the joint in the same direction you will be soldering. Continue flashing off the torch and touching the solder wire to the joint until the solder begins to melt. Keeping the molten pool small enough to work with is a major problem with soldering. The flame must be flashed off frequently to prevent overheating. When the joint is completed, the solder should be uniform. Repeat this

practice until it can be made without defects. Turn off the cylinders, bleed the hoses, back out the regulator adjusting screws, and clean your work area when you are finished.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 33-18

Soldered Lap Joint

Using the same equipment, materials, and setup as listed in Practice 33-17, you will solder a lap joint in the horizontal position.

Tack the pieces of metal together as shown in **Figure 33-63**. Apply the flux and heat the metal slowly, checking the temperature by touching the solder wire to the metal often. When the work gets hot enough, flash the flame off frequently to prevent overheating and proceed along the joint. When the joint is completed, the solder should be uniform. Repeat this practice until it can be made without defects. Turn off the cylinders, bleed the hoses, back out the regulator adjusting screws, and clean your work area when you are finished.

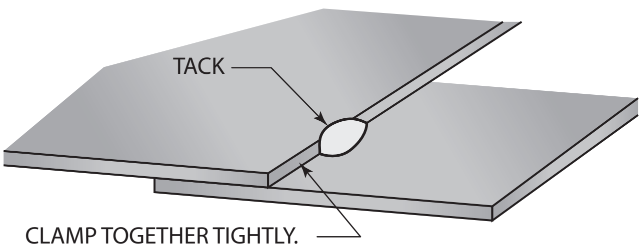


FIGURE 33-63 Tacking metal together for soldering.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 33-19

Soldering Copper Pipe, 2G Vertical Down Position

Using a properly lit and adjusted torch, a piece of 1/2-in. to 1-in. (13-mm to 25-mm) copper pipe, a copper pipe fitting, steel wool, flux, and tin-lead or tin-antimony solder wire, you will solder a pipe joint in the vertical down position, **Figure 33-64**.

Clean the pipe and fitting using steel wool and apply the flux to both parts. Slide the fitting onto the pipe and twist the fitting to ensure that the flux is applied completely around the inside of the joint.

Make a bend in the solder wire approximately 3/4 in. (19 mm) from the end. This will give you a gauge so that you do not put too much solder in the joint. Excessive solder will flow inside the pipe, and it may cause problems to the system later.

Heat the pipe and the fitting with the torch. As the parts become hot, keep checking the parts with the solder wire so that you know when they reach the correct temperature. When the solder starts to wet, remove the flame and wipe the joint with the end of the solder wire, **Figure 33-65**. Next, heat the fitting more than the pipe so that the solder will be drawn into the joint. Rewipe the joint with the solder as needed. There should be a small fillet of solder around the joint. This fillet adds very little strength to the joint, but it is an easy way to make sure that the joint is leak-free.

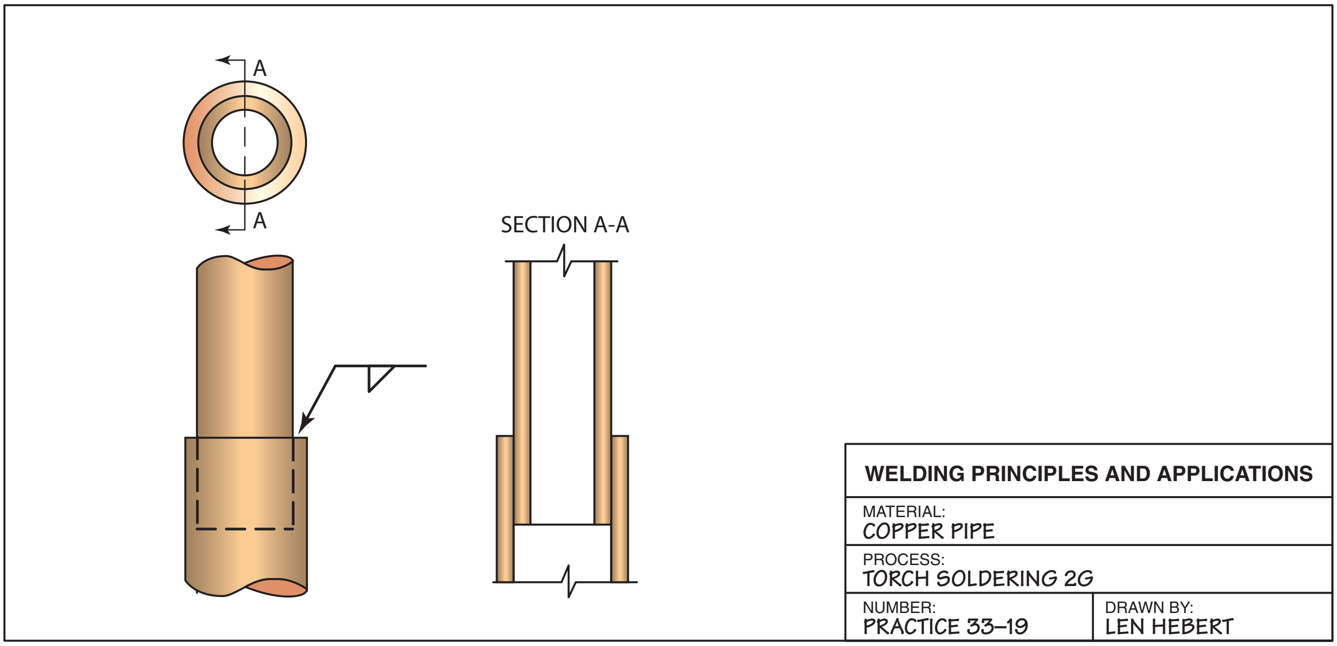


FIGURE 33-64 2G vertical down position.

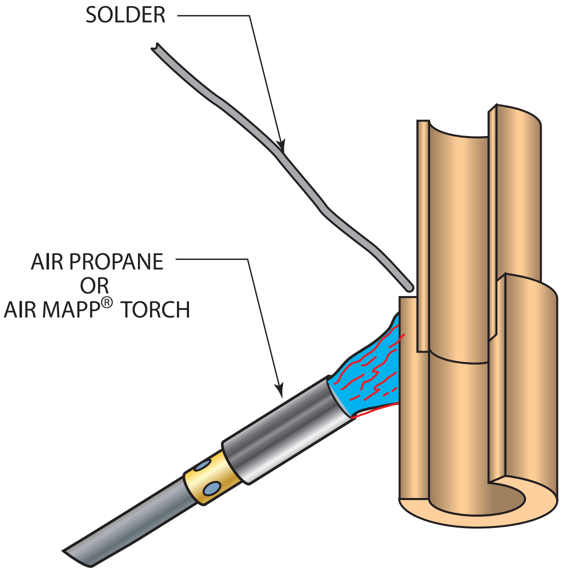


FIGURE 33-65 Soldering copper fitting to copper pipe.

After the pipe has cooled, notch it diagonally with a hacksaw, put a screwdriver in the cut, and twist the joint apart, **Figure 33-66**. With the joint separated, check for: (1) complete penetration; (2) small porosity caused by overheating the solder; (3) drops of solder inside of the pipe; or (4) other defects. Repeat this practice until it can be done without defects. Turn off the cylinders, bleed the hoses, back out the regulator adjusting screws, and clean your work area when you are finished.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 33-20

Soldering Copper Pipe, 1G Position

Using the same equipment and setup as listed in Practice 33-19, make a soldered joint with the pipe held horizontally, **Figure 33-67**. Test the joint as before and

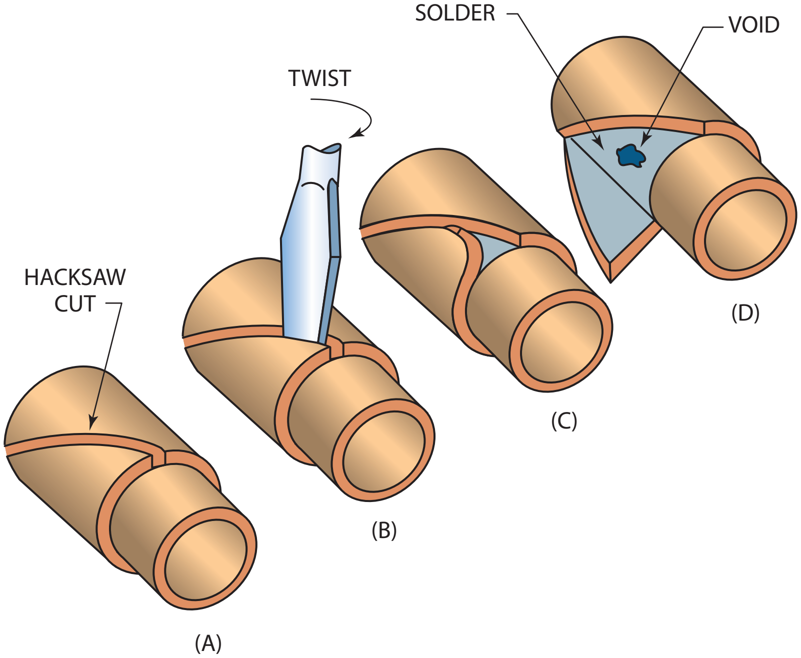


FIGURE 33-66 (A) Use a hacksaw to cut a groove through the outside copper pipe. (B) Carefully push a flat blade screwdriver into the saw cut groove. (C) Twist the blade to open up the groove. (D) Unwrap the outer copper pipe to reveal the solder in the joint.

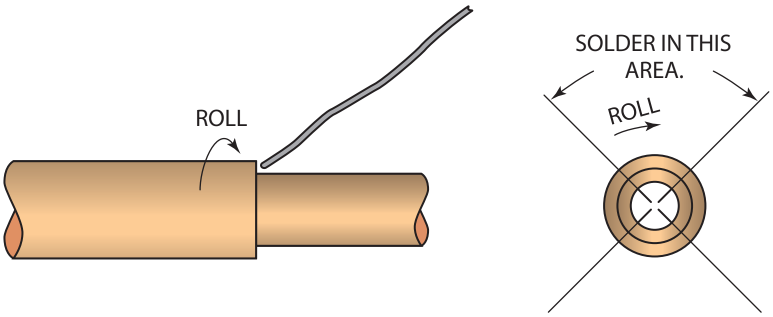


FIGURE 33-67 1G soldering.

repeat as necessary until it passes the test. Turn off the cylinders, bleed the hoses, back out the regulator adjusting screws, and clean your work area when you are finished.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 33-21

Soldering Copper Pipe, 4G Vertical Up Position

Using the same equipment and setup as listed in Practice 33-19, make a soldered joint with the pipe held in the vertical position with the solder flowing uphill. Test the joint as before and repeat as necessary until it can be made without defects. Turn off the cylinders, bleed the hoses, back out the regulator adjusting screws, and clean your work area when you are finished.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

PRACTICE 33-22

Soldering Aluminum to Copper

Using a properly lit and adjusted torch, a piece of aluminum plate, a copper penny, steel wool, flux, and tin-lead or tin-antimony solder wire, you will tin both the aluminum and the copper with solder and then join both together.

The surface of the aluminum must be clean and free of paint, oils, dirt, and coatings such as anodizes. Hold the flame on the aluminum until it warms up slightly. Hold the solder in the flame and allow a small amount to melt and drop on the aluminum plate; do not add flux, **Figure 33-68**. Move the flame off the plate and rub the liquid solder with the steel wool. Be careful not to burn your fingers or allow the flame to touch the steel wool. The solder should be stuck in the steel wool when it is lifted off the plate. Alternately heat the plate and rub it with the steel wool solder. When the plate becomes hot enough, it will melt the solder and the solder will tin the aluminum surface, **Figure 33-69**.

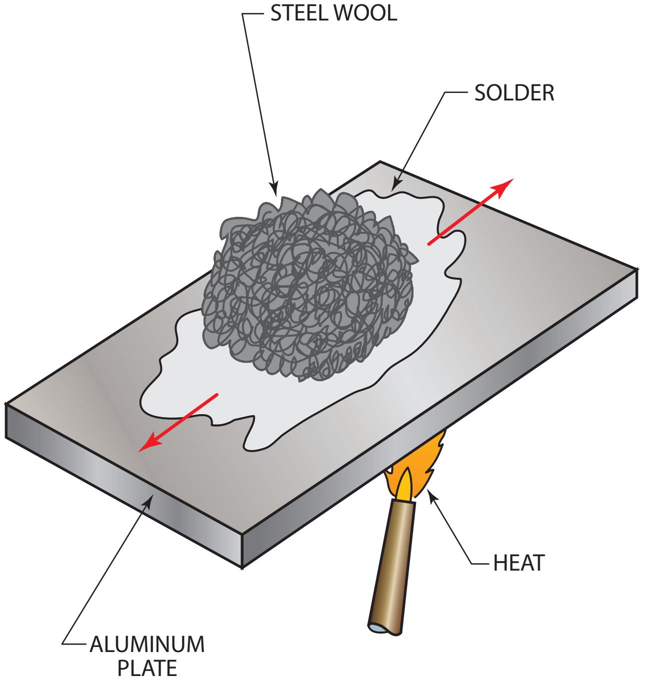


FIGURE 33-68 Tinning aluminum with solder.

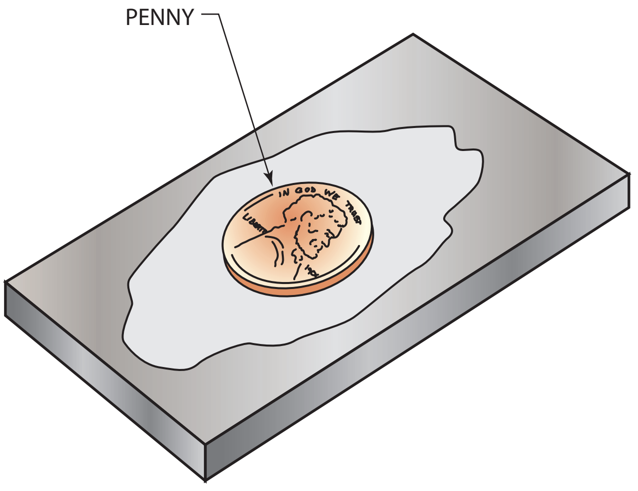


FIGURE 33-69 Copper penny soldered to aluminum.

Use some flux and solder, and tin the penny. Place the penny on the aluminum plate so the areas of solder on both the penny and plate are touching each other. Heat the two until the solder melts and flows out from between the penny and plate. When the parts cool, to check the bond, try to break the joint apart.

This process will work on other types of metals that have a strong oxide layer that prevents the solder from bonding. By breaking the oxide layer free with the mechanical action of the steel wool, the metals can join. This process can allow a copper patch over an aluminum tube such as those used in air-conditioning or refrigeration, **Figure 33-70**. Turn off the cylinders, bleed the hoses, back out the regulator adjusting screws, and clean your work area when you are finished.

Complete a copy of the "Student Welding Report" listed in Appendix I or provided by your instructor. ◆

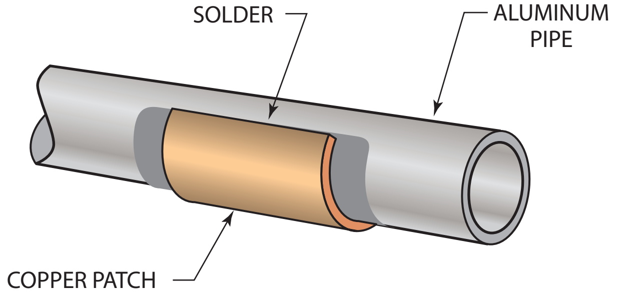


FIGURE 33-70 Aluminum pipe patch.

Summary

Brazing and soldering are processes that have many great advantages but are often overlooked when a joining process is being selected. For example, brazing and soldering are excellent processes for portable applications. In addition, their versatility makes them great choices for many jobs in which good joint design will result in joint strength equal to or higher than that of welding. The ability to join many different materials with a limited variety of fluxes and filler metals reduces the need for a large inventory of materials, which can result in great cost-savings for a small business, home shop, or farm.

For example, solder can be used on the threads of a bolt on an off-road vehicle to act as a locknut to keep it from vibrating off. To remove the nut, one needs to only heat the threads, and it unscrews easily. Soldering can then be either a permanent or a temporary attaching process.

Be creative in the way you apply these processes. They can be very beneficial to you and your employer.

Review

1. Explain the difference between brazing and soldering.
2. How does capillary action separate brazing from braze welding?
3. Why can brazing be both a permanent and a temporary joining method?
4. Why is it less likely that a part would be damaged with brazing than with welding?
5. What is the effect of joint spacing on joint tensile strength?
6. Why are braze joints subject to fatigue failure?
7. Do all braze joints resist corrosion? Give an example.
8. What are the three primary functions that a flux must perform?
9. In what forms are fluxes available?
10. How can liquid fluxes be delivered to the joint through the torch?
11. How do fluxes react with the base metal?
12. How are brazing and soldering methods grouped?
13. What are the advantages of torch soldering?
14. What are the advantages of furnace brazing?
15. How does the induction brazing method heat the part being brazed?
16. What soldering process can be used to join parts and provide a protective coating to the part at the same time?
17. What brazing or soldering process uses a machine similar to a spot welder to produce the heat required to make a joint?
18. What is a metal alloy?
19. Why must parts not be moved as they cool through the paste range?
20. Why must you not use tin-lead solders on water piping?
21. Using Table 33-3, determine the approximate temperature at which a mixture of 90% tin with 10% lead would become 100% liquid.
22. What is a major use of tin-antimony solder?
23. What solder alloy can retain its strength at elevated temperatures?
24. Why do brazing alloys use letters such as CuZn to identify the metal?
25. What is the white smoke that can be given off from copper-zinc brazing alloy?
26. Which copper-zinc brazing alloy could be used to join or repair each of the following:
    - **a.** cast iron
    - **b.** build up wear surfaces
    - **c.** malleable iron
    - **d.** naval brass
27. Why should copper-phosphorus not be used on fittings with ferrous substrates?
28. Silver-copper alloys can be used to join which metals?
29. Which nickel alloy would be best for joining the following:
    - **a.** poorly fitting joints
    - **b.** honeycomb structures
    - **c.** jet engine parts
    - **d.** corrosive applications
30. Why does BCu-2 brazing alloy use an organic compound mixed with copper?
31. Using Table 33-6, determine the ideal joint spacings for the following braze alloys:

- **a.** BCuZn
- **b.** BAlSi
- **c.** BCuP

32. What indicates that you have overheated the solder flux on copper?

33. How can the size of a braze bead be controlled?

34. Why is brazing a better process than welding to rebuild some surfaces?

Appendix

Appendix I

Student Welding Report

Appendix I

Student Welding Report and/or SENSE Record

Student Name:______________________________Date:____________Class:_________Overall Gread:________

Practice #:________________, Is this an AWS SENSE Workmanship Sample: Yes___ No ___, AWS SENSE Drawing #: ____________

Welding Parameters

Process(s): ________________ Volts: _____, Amps: _____, or WIRE FEED SPEED for GMAW/FCAW: _________, Shielding Gas(s):________

Filler Metal AWS #: ______________, Diameter: ___________, Shielding Gas CFH: ___________, GTAW Tungsten Type:_________

Base Metal

Type of Metal:________________, Plate Thickness: _______, Pipe Diameter: _______, Schedule: ______, Welding Position: ______

Metal Preparation

Joint Type(s):___________________Weld Grooves Angle: ________________, Root Face: __________, Root Gap: _________

VISUAL INSPECTION REPORT

Criteria According to AWS QC-10 and AWS QC-11

Cracks: Yes ____ No ____, Incomplete Fusion: Yes ____ No ____, Incomplete Joint Penetration: Yes ____ No ____, Overlap: Yes ____ No ____

Undercut: Yes __ No __, Depth 1.___ 2.___ 3.___ 4.___, Acceptable Yes __ No __, Porosity: 1.___ 2.___ 3.___ 4.___, Acceptable Yes __ No __

BEND TEST REPORT

Face Bend	Indication Measurement	Pass Fail	Root Bend	Indication Measurement	Pass Fail
1.			2.		
3.			4.		
Side Bend	Indication Measurement	Pass Fail	Side Bend	Indication Measurement	Pass Fail
1.			2.		
3.			4.		

WELD TEST RESULTS

Weld: Pass ______ Fail ______ Grade:_________ Date:_____________

Student Signature:______________________________ Instructor Signature: ________________________________

AWS SENSE ACHIEVEMENT RECORD

Module	Required	Topic	Grade	Date	Instructor Initials
1.	Yes	Occupational Orientation			
2.	Yes	Safety and Health of Welders (100% Grade Required)			
3.	Yes	Drawing and Welding Symbol Interpretation			
8.	Yes	Thermal Cutting Processes (Units 1 & 3 Minimum)			
9.	Yes	Welding Inspection and Testing			
		Plus One or More of the Following			
4.		SMAW			
5.		GMAW			
6.		FCAW			
7.		GTAW			

Comments:

Appendix II

SENSE

Appendix II
Student SENSE Performance Qualification Test Drawing 1

REVISIONS				
ZONE	REV	DESCRIPTION	DATE	APPROVED

INCH	MM
1/16	1.6
1/8	3.2
1/4	6.4
1/2	12.7
1	25.4

Notes:

Performance Qualification Test Information

SIZE	QC NO:	DWG NO:	REV:
APPROVED:	DATE:	SHEET: 1 of __	

TOLERANCES (Unless Otherwise Specified)
DO NOT SCALE DRAWING
Fractions: ±1/16″ Angles: + 10°,-5°

DR BY:	DATE:
CHK BY:	DATE:

Appendix III

SENSE

Appendix III
Student SENSE Performance Qualification Test Drawing 2

NOTES:

ID	QTY	SIZE	METRIC CONVERSION

Performance Qualification Test Information

DATE: SCALE: DWG #:

DR BY: Tolerances: (Unless otherwise specified)
DRAWING NOT TO SCALE

APP BY: Fractions: ± 1/16″ Angles: + 10°, -5°

Appendix IV

Conversion of Decimal-Inches to Millimeters and Fractional Inches to Decimal-Inches and Millimeters

Inches dec	mm	Inches dec	mm
0.01	0.2540	0.51	12.9540
0.02	0.5080	0.52	13.2080
0.03	0.7620	0.53	13.4620
0.04	1.0160	0.54	13.7160
0.05	1.2700	0.55	13.9700
0.06	1.5240	0.56	14.2240
0.07	1.7780	0.57	14.4780
0.08	2.0320	0.58	14.7320
0.09	2.2860	0.59	14.9860
0.10	2.5400	0.60	15.2400
0.11	2.7940	0.61	15.4940
0.12	3.0480	0.62	15.7480
0.13	3.3020	0.63	16.0020
0.14	3.5560	0.64	16.2560
0.15	3.8100	0.65	16.5100
0.16	4.0640	0.66	16.7640
0.17	4.3180	0.67	17.0180
0.18	4.5720	0.68	17.2720
0.19	4.8260	0.69	17.5260
0.20	5.0800	0.70	17.7800
0.21	5.3340	0.71	18.0340
0.22	5.5880	0.72	18.2880
0.23	5.8420	0.73	18.5420
0.24	6.0960	0.74	18.7960
0.25	6.3500	0.75	19.0500
0.26	6.6040	0.76	19.3040
0.27	6.8580	0.77	19.5580
0.28	7.1120	0.78	19.8120
0.29	7.3660	0.79	20.0660
0.30	7.6200	0.80	20.3200
0.31	7.8740	0.81	20.5740
0.32	8.1280	0.82	20.8280
0.33	8.3820	0.83	21.0820
0.34	8.6360	0.84	21.3360
0.35	8.8900	0.85	21.5900
0.36	9.1440	0.86	21.8440
0.37	9.3980	0.87	22.0980
0.38	9.6520	0.88	22.3520
0.39	9.9060	0.89	22.6060
0.40	10.1600	0.90	22.8600
0.41	10.4140	0.91	23.1140
0.42	10.6680	0.92	23.3680
0.43	10.9220	0.93	23.6220
0.44	11.1760	0.94	23.8760
0.45	11.4300	0.95	24.1300
0.46	11.6840	0.96	24.3840
0.47	11.9380	0.97	24.6380
0.48	12.1920	0.98	24.8920
0.49	12.4460	0.99	25.1460
0.50	12.7000	1.00	25.4000

Inches frac	Inches dec	mm	Inches frac	Inches dec	mm
1/64	0.015625	0.3969	33/64	0.515625	13.0969
1/32	0.031250	0.7938	17/32	0.531250	13.4938
3/64	0.046875	1.1906	35/64	0.546875	13.8906
1/16	0.062500	1.5875	9/16	0.562500	14.2875
5/64	0.078125	1.9844	37/64	0.578125	14.6844
3/32	0.093750	2.3812	19/32	0.593750	15.0812
7/64	0.109375	2.7781	39/64	0.609375	15.4781
1/8	0.125000	3.1750	5/8	0.625000	15.8750
9/64	0.140625	3.5719	41/64	0.640625	16.2719
5/32	0.156250	3.9688	21/32	0.656250	16.6688
11/64	0.171875	4.3656	43/64	0.671875	17.0656
3/16	0.187500	4.7625	11/16	0.687500	17.4625
13/64	0.203125	5.1594	45/64	0.703125	17.8594
7/32	0.218750	5.5562	23/32	0.718750	18.2562
15/64	0.234375	5.9531	47/64	0.734375	18.6531
1/4	0.250000	6.3500	3/4	0.750000	19.0500
17/64	0.265625	6.7469	49/64	0.765625	19.4469
9/32	0.281250	7.1438	25/32	0.781250	19.8437
19/64	0.296875	7.5406	51/64	0.796875	20.2406
5/16	0.312500	7.9375	13/16	0.812500	20.6375
21/64	0.328125	8.3344	53/64	0.828125	21.0344
11/32	0.343750	8.7312	27/32	0.843750	21.4312
23/64	0.359375	9.1281	55/64	0.859375	21.8281
3/8	0.375000	9.5250	7/8	0.875000	22.2250
25/64	0.390625	9.9219	57/64	0.890625	22.6219
13/32	0.406250	10.3188	29/32	0.906250	23.0188
27/64	0.421875	10.7156	59/64	0.921875	23.4156
7/16	0.437500	11.1125	15/16	0.937500	23.8125
29/64	0.453125	11.5094	61/64	0.953125	24.2094
15/32	0.468750	11.9062	31/32	0.968750	24.6062
31/64	0.484375	12.3031	62/64	0.984375	25.0031
1/2	0.500000	12.7000	1	1.000000	25.4000

For converting decimal-inches in "thousandths," move decimal point in both columns to left.

Appendix V

Conversion Factors: U.S. Customary (Standard) Units and Metric Units (SI)

TEMPERATURE

Units

°F (each 1° change)	= 0.555°C (change)
°C (each 1° change)	= 1.8°F (change)
32°F (ice freezing)	= 0°Celsius
212°F (boiling water)	= 100°Celsius
–460°F (absolute zero)	= 0° Rankine
–273°C (absolute zero)	= 0° Kelvin

Conversions

°F to °C	________ °F – 32	=	________ × 0.555	=	________ °C
°C to °F	________ °C × 1.8	=	________ + 32	=	________ °F

LINEAR MEASUREMENT

Units

1 inch	= 25.4 millimeters
1 inch	= 2.54 centimeters
1 millimeter	= 0.0394 inch
1 centimeter	= 0.3937 inch
12 inches	= 1 foot
3 feet	= 1 yard
5280 feet	= 1 mile
10 millimeters	= 1 centimeter
10 centimeters	= 1 decimeter
10 decimeters	= 1 meter
1000 meters	= 1 kilometer

Conversions

in. to mm	________ in.	× 25.4	=	________ mm
in. to cm	________ in.	× 2.54	=	________ cm
ft to mm	________ ft	× 304.8	=	________ mm
ft to m	________ ft	× 0.3048	=	________ m
mm to in.	________ mm	× 0.0394	=	________ in.
cm to in.	________ cm	× 0.3937	=	________ in.
mm to ft	________ mm	× 0.00328	=	________ ft
m to ft	________ m	× 3.28	=	________ ft

AREA MEASUREMENT

Units

1 sq in.	= 0.0069 sq ft
1 sq ft	= 144 sq in.
1 sq ft	= 0.111 sq yd
1 sq yd	= 9 sq ft
1 sq in.	= 645.16 sq mm
1 sq mm	= 0.00155 sq in.
1 sq cm	= 100 sq mm
1 sq m	= 1000 sq cm

Conversions

sq in. to sq mm	________ sq in. × 645.16	=	________ sq mm
sq mm to sq in.	________ sq mm × 0.00155	=	________ sq in.

VOLUME MEASUREMENT

Units

1 cu in.	= 0.000578 cu ft
1 cu ft	= 1728 cu in.
1 cu ft	= 0.03704 cu yd
1 cu ft	= 28.32 L
1 cu ft	= 7.48 gal (U.S.)
1 gal (U.S.)	= 3.737 L
1 cu yd	= 27 cu ft
1 gal	= 0.1336 cu ft
1 cu in.	= 16.39 cu cm
1 L	= 1000 cu cm

Appendix V

Conversion Factors: U.S. Customary (Standard) Units and Metric Units (SI) *(Continued)*

1 L	= 61.02 cu in.
1 L	= 0.03531 cu ft
1 L	= 0.2642 gal (U.S.)
1 cu yd	= 0.769 cu m
1 cu m	= 1.3 cu yd

Conversions

cu in. to L	________	cu in.	× 0.01638	=	________	L
L to cu in.	________	L	× 61.02	=	________	cu in.
cu ft to L	________	cu ft	× 28.32	=	________	L
L to cu ft	________	L	× 0.03531	=	________	cu ft
L to gal	________	L	× 0.2642	=	________	gal
gal to L	________	gal	× 3.737	=	________	L

WEIGHT (MASS) MEASUREMENT

Units

1 oz	= 0.0625 lb
1 lb	= 16 oz
1 oz	= 28.35 g
1 g	= 0.03527 oz
1 lb	= 0.0005 ton
1 ton	= 2000 lb
1 oz	= 0.283 kg
1 lb	= 0.4535 kg
1 kg	= 35.27 oz
1 kg	= 2.205 lb
1 kg	= 1000 g

Conversions

lb to kg	________	lb	× 0.4535	=	________	kg
kg to lb	________	kg	× 2.205	=	________	lb
oz to g	________	oz	× 0.03527	=	________	g
g to oz	________	g	× 28.35	=	________	oz

PRESSURE and FORCE MEASUREMENTS

Units

1 psig	= 6.8948 kPa
1 kPa	= 0.145 psig
1 psig	= 0.000703 kg/sq mm
1 kg/sq mm	= 6894 psig
1 lb (force)	= 4.448 N
1 N (force)	= 0.2248 lb

Conversions

psig to kPa	________	psig	× 6.8948	=	________	kPa
kPa to psig	________	kPa	× 0.145	=	________	psig
lb to N	________	lb	× 4.448	=	________	N
N to lb	________	N	× 0.2248	=	________	lb

VELOCITY MEASUREMENTS

Units

1 in./sec	= 0.0833 ft/sec
1 ft/sec	= 12 in./sec
1 ft/min	= 720 in./sec
1 in./sec	= 0.4233 mm/sec
1 mm/sec	= 2.362 in./sec
1 cfm	= 0.4719 L/min
1 L/min	= 2.119 cfm

Conversions

ft/min to in./sec	________	ft/min	× 720	=	________	in./sec
in./min to mm/sec	________	in./min	× 0.4233	=	________	mm/sec
mm/sec to in./min	________	mm/sec	× 2.362	=	________	in./min
cfm to L/min	________	cfm	× 0.4719	=	________	L/min
L/min to cfm	________	L/min	× 2.119	=	________	cfm

Appendix VI

Abbreviations and Symbols

U.S. Customary (Standard) Units

˚F	= degrees Fahrenheit
˚R	= degrees Rankine = degrees absolute F
lb	= pound
psi	= pounds per square inch = lb per sq in.
psia	= pounds per square inch absolute = psi + atmospheric pressure
in.	= inches = i = "
ft	= foot or feet = f = '
sq in.	= square inch = in.^{2}
sq ft	= square foot = ft^2
cu in.	= cubic inch = in.^{3}
cu ft	= cubic foot = ft^3
ft-lb	= foot-pound
ton	= ton of refrigeration effect
qt	= quart

Metric Units (SI)

˚C	= degrees Celsius
˚K	= degrees Kelvin
mm	= millimeter
cm	= centimeter
cm^2	= centimeter squared
cm^3	= centimeter cubed
dm	= decimeter
dm^2	= decimeter squared
dm^3	= decimeter cubed
m	= meter
m^2	= meter squared
m^3	= meter cubed
L	= liter
g	= gram
kg	= kilogram
J	= joule
kJ	= kilojoule
N	= newton
Pa	= pascal
kPa	= kilopascal
W	= watt
kW	= kilowatt
MW	= megawatt

Miscellaneous Abbreviations

P	= pressure
h	= hours
sec	= seconds
D	= diameter
r	= radius of circle
A	= area
π	= 3.1416 (a constant used in determining the area of a circle)
V	= volume
°	= infinity

Appendix VII

Metric Conversion Approximations

Metric Conversion Approximations
1/4 inch = 6 mm
1/2 inch = 13 mm
3/4 inch = 18 mm
1 inch = 25 mm
2 inches = 50 mm
1/2 gal = 2 L
1 gal = 4 L
1 lb = 1/2 K
2 lb = 1 K
1 psig = 7 kPa
1°F = 2°C

Appendix VIII

Pressure Conversion

psi	kPa	psi	kPa
1	7 (6.9)	100	690 (689)
2	14 (13.7)	110	760 (758)
3	20 (20.6)	120	820 (827)
4	30 (27.5)	130	900 (896)
5	35 (34.4)	140	970 (965)
6	40 (41.3)	150	1030 (1034)
7	50 (48.2)	160	1100 (1103)
8	55 (55.1)	170	1170 (1172)
9	60 (62.0)	180	1240 (1241)
10	70 (69.9)	190	1310 (1310)
15	100 (103)	200	1380 (1379)
20	140 (137)	225	1550 (1551)
25	170 (172)	250	1720 (1723)
30	200 (206)	275	1900 (1896)
35	240 (241)	300	2070 (2068)
40	280 (275)	325	2240 (2240)
45	310 (310)	350	2410 (2413)
50	340 (344)	375	2590 (2585)
55	380 (379)	400	2760 (2757)
60	410 (413)	450	3100 (3102)
65	450 (448)	500	3450 (3447)
70	480 (482)	550	3790 (3792)
75	520 (517)	600	4140 (4136)
80	550 (551)	650	4480 (4481)
85	590 (586)	700	4830 (4826)
90	620 (620)	750	5170 (5171)
95	660 (655)	800	5520 (5515)
		850	5860 (5860)
		900	6210 (6205)
		950	6550 (6550)
		1000	6890 (6894)

Pounds per square inch (psi) converted to kilopascals (kPa). One psi equals 6.8948 kPa. In most applications the conversion from standard units of pressure to SI units can be rounded to an even number. The number in parentheses is the value before it is rounded off.

Appendix IX

Welding Codes and Specifications

A *welding code* is a detailed listing of the rules or principles that are to be applied to a specific classification or type of product.

A *welding specification* is a detailed statement of the legal requirements for a specific classification or type of product. Products manufactured to code or specification requirements commonly must be inspected and tested to ensure compliance.

A number of agencies and organizations publish welding codes and specifications. The application of the particular code or specification to a weldment can be the result of one or more of the following requirements:

- Local, state, or federal government regulations
- Bonding or insuring company
- End-user (customer) requirements
- Standard industrial practices

The three most popular codes are:

#1104, American Petroleum Institute—Used for pipelines

Section IX, American Society of Mechanical Engineers—Used for pressure vessels

D1.1, American Welding Society—Used for bridges and buildings

The following organizations publish welding codes and/or specifications.

AAR
(Association of American Railroads)

AASHTO
(American Association of State Highway and Transportation Officials)

AISC
(American Institute of Steel Construction)

ANSI
(American National Standards Institute)

API
(American Petroleum Institute)

AREMA
(American Railway Engineering and Maintenance-of-Way Association)

ASME
(American Society of Mechanical Engineers)

AWS
(American Welding Society)

AWWA
(American Water Works Association)

MIL
(Department of Defense)

SAE
(Society of Automotive Engineers)

Appendix X

Welding Associations and Organizations

AA
(Aluminum Association)

AASHTO
(American Association of State Highway and Transportation Officials)

AGA
(American Gas Association)

AIME
(American Institute of Mining, Metallurgical and Petroleum Engineering)

AISC
(American Institute of Steel Construction)

AISI
(American Iron and Steel Institute)

ANS
(American Nuclear Society)

ANSI
(American National Standards Institute)

API
(American Petroleum Institute)

ASCE
(American Society of Civil Engineers)

ASME
(American Society of Mechanical Engineers)

ASNT
(American Society for Nondestructive Testing)

ASTM
(American Society for Testing and Materials)

AWS
(American Welding Society)

CWB
(Canadian Welding Bureau)

EWI
(Edison Welding Institute)

IIW
(International Institute of Welding)

NSC
(National Safety Council)

PFI
(Pipe Fabrication Institute)

SAE
(Society of Automotive Engineers)

SME
(Society of Manufacturing Engineers)

TWI
(The Welding Institute)

WRC
(Welding Research Council)

Glossary

The terms and definitions in this glossary are extracted from the American Welding Society publication AWS A3.0-80 Welding Terms and Definitions. The terms with an asterisk are from a source other than the American Welding Society. *Note:* The English term and definition are given first, followed by the same term and definition in Spanish.

A

***abrasives.** Materials that are usually sharp and are used to clean or grind a surface. They may be used as a powder such as sand to blast the surface or they may be formed into disks or stones to be used by a grinder.
abrasivos. Materiales que son por lo general ásperos y que se utilizan para limpiar o pulir superficies. Pueden venir en polvo, como arena, para bruñir las superficies, o en forma de discos o piedras para ser usados por una esmeriladora.

***absolute pressure.** The sum of the gauge pressure and the atmospheric pressure.
presión absoluta. La suma de la presión manómetro y la presión atmosférica.

absorptive lens. A filter lens designed to attenuate the effects of transmitted and reflected light.
lente absorbente. Un lente de filtro diseñado para disminuir los efectos de la luz y la reflexión de la luz extraviada.

acceptable criteria. Agreed upon standards that must be satisfactorily met.
criterios aceptables. Las normas sobre las que se ha llegado a un acuerdo y que deben cumplirse en forma satisfactoria.

acceptable weld. A weld that meets all the requirements and the acceptance criteria.
soldadura aceptable. Una soldadura que satisface los requisitos y el criterio aceptable prescribida por las especificaciónes de la soldadura.

***acetone.** A fragrant liquid chemical used in acetylene cylinders. The cylinder is filled with a porous material and acetone is then added to fill. Acetylene is then added and absorbed by the acetone, which can absorb up to 28 times its own volume of the gas.
acetona. Un liquido fragante químico que se usa en los cilindros del acetileno. El cilindro se llena de un material poroso y luego se le agrega la acetona hasta que se llene. El acetileno es absorbido por la acetona, la cual puede absorber 28 veces el propio volumen del gas.

***acetylene (C_2H_2).** A fuel gas used for welding and cutting. It is produced as a result of the chemical reaction between calcium carbide and water. The chemical formula for acetylene is C_2H_2. It is colorless, is lighter than air, and has a strong garlic-like smell. Acetylene is unstable above pressures of 15 psig (1.05 kg/cm^2 g). When burned in the presence of oxygen, acetylene produces one of the highest flame temperatures available.
acetileno (C_2H_2). Un gas combustible que se usa para soldar y cortar. Es producido a consecuencia de una reacción química de agua y calcio y carburo. La fórmula química para el acetileno es C_2H_2. No tiene color, es más ligero que el aire, y tiene un olor fuerte como a ajo. El acetileno es inestable en presiones más altas de 15 psig (1.05 kg/cm^2 g). Cuando se quema en presencia del oxígeno, el acetileno produce una de las llamás con una temperatura más alta que la que se utiliza.

***acicular structure.** A fine micrograin structure found in rapidly cooled steel.
***estructura acicular.** Una estructura micro granulada fina que se encuentra en el acero que se ha enfriado con rapidez.

actual throat. See throat of a fillet weld.
garganta actual. Vea garganta de soldadura filete.

***adaptable.** Capable of making self-directed corrections; in a robot, this is often accomplished with visual, force, or tactile sensors.
adaptable. Capaz de hacer correcciones por instrucción propia de un robot, esto se lleva a cabo con sensores tangibles visuales, o de fuerza.

air acetylene welding (AAW). An oxyfuel gas welding process that uses an air-acetylene flame. The process is used without the application of pressure. This is an obsolete or seldom used process.
soldadura de aire acetileno (AAW). Un proceso de soldar con gas (oxi/combustible) que usa aire-acetileno sin aplicarse presión. Un proceso anticuado que es una rareza.

air carbon arc cutting (CAC-A). A carbon arc cutting process variation removing molten metal with a jet of air.
arco de carbón con aire (CAC-A). Un proceso de cortar con arco de carbón variante que quita el metal derretido con un chorro de aire.

***allotropic metals.** Metals that have specific lattice or crystal structures that form when the metal is cool and that change within the solid metal as it is heated and before it melts.
metales alotrópicos. Metales que tienen un determinado enrejado o estructuras cristalinas que se forman cuando el metal está frío y cambian dentro del metal sólido mientras se lo calienta y antes de que éste se derrita.

allotropic transformation. A change in the crystalline lattice pattern of a metal due to a change in temperature.
transformación alotropico. Un cambio en el modelo cristalino enrejado del metal debido a un cambio en la temperatura.

***alloy.** A metal with one or more elements added to it, resulting in a significant change in the metal's properties.
aleación. Un metal en que se le agrega uno o más elementos resultando en un cambio significante en las propiedades del metal.

***alloy steels.** Steels that may contain any number of a variety of elements that are used to change the mechanical properties of steel. The amount of the added elements can range from 1% to 50%.
aleación de acero. Acero que contiene cualquier número de una variedad de elementos que se usan para cambiar las propiedades mecánicas del acero. La cantidad de elementos agregados puede variar entre el 1% al 50%.

***alloying elements.** Elements in the flux that mix with the filler metal and become part of the weld metal. Major alloying elements are molydenum, nickel, chromium, manganese, and vanadium.
elementos de mezcla. Elementos en el flujo que se mezclan con el metal para rellenar y formar parte del metal soldado. Los elementos principales de mezcla son molibdeno, niquel, cromo, manganeso y vanadio.

***all-weld-metal test specimen.** A test specimen with the reduced section composed wholly of weld metal.
prueba de metal soldado. Una prueba con una sección reducida compuesta totalmente del metal de la soldadura.

***alphabet of lines.** Lines are the language of drawing; they are used to represent various parts of the object being illustrated. The various line types are collectively known as the Alphabet of Lines.
alfabeto de líneas. Las líneas son el idioma del dibujo; se usan para representar las diferentes partes de un objeto que se ilustra. El conjunto de los distintos tipos de líneas se conoce como Alfabeto de Líneas.

***aluminum.** A soft silvery-gray highly thermally and electrically conductive metal that naturally resists corrosion.
aluminio. Metal blando de color gris plateado que es buen conductor del calor y de la electricidad y que resiste naturalmente la corrosión.

***American Welding Society. (AWS).** Organization that promotes the art and science of welding and that publishes international codes and standards.
Sociedad Americana de Soldadores. (AWS). Organización que promueve el arte y la ciencia de la soldadura y que publica códigos y estándares internacionales.

***amperage.** A measurement of the rate of flow of electrons; amperage controls the size of the arc.
amperaje. Una medida de la proporción de la corriente de electrones; el amperaje controla el tamaño del arco.

amperage range. The lower and upper limits of welding power, in amperage, that can be produced by a welding machine or used with an electrode or by a process.
rango de amperaje. Los límites máximos y mínimos de poder de soldadura (en amperaje) que puede tener una máquina para soldar o que pueden usarse con un electrodo o a través de un proceso.

angle of bevel. See preferred term bevel angle.
ángulo del bisel. Es preferible que vea el término ángulo del bisel.

***anode.** Material with a lack of electrons; thus, it has a positive charge.
ánodo. Un material que carece electrones; por eso tiene una carga positiva.

arc blow. The deflection of arc from its normal path because of magnetic forces.
soplo del arco. Desviación de un arco eléctrico de su senda normal a causa de fuerzas magnéticas.

arc braze welding (ABW). A braze welding process variation using an electric arc as the heat source.
soldadura fuerte aplicada por arco (ABW). Un proceso de soldadura fuerte donde el calor requerido es obtenido de un arco eléctrico.

arc cutting (AC). A group of thermal cutting processes that severs or removes metal by melting with the heat of an arc between an electrode and the workpiece.
corte con arco (AC). Un grupo de procesos termales para cortar que desúne o quita el metal derretido con el calor del arco en medio del electrodo y la pieza de trabajo.

arc cutting electrodes. An electrode that has a flux covering that allows the core wire to burn back inside so it creates a strong jetting action which blows out the molten metal created by the arc. See arc cutting.
electrodos para corte con arco. Electrodos con fundente que permiten que el núcleo de éstos se queme desde adentro para crear presiones que soplan el metal derretido que se crea por el arco. Ver corte con arco.

arc force. The axial force developed by a plasma.
fuerza del arco. La fuerza axial desarrollada por la plasma.

arc gouging. Thermal gouging that uses an arc cutting process variation to form a bevel or groove.
gubiadura con arco. Gubiadura termal que usa un proceso variante de corte con arco para formar un bisel o ranura.

arc length. The length from the tip of the welding electrode to the adjacent surface of the weld pool.
largura del arco. La distancia de la punta del electrodo a la superficie que colinda con el charco de la soldadura.

arc plasma. A gas heated by an arc to at least a partially ionized condition, enabling it to conduct an electric current. See also plasma.
arco de plasma. Un estado de la materia encontrado en la región de una descarga eléctrica (arco). Vea también plasma.

arc spot weld. A spot weld made by an arc welding process.
soldadura de puntos por arco. Una soldadura de punto hecha por un proceso de soldadura de arco.

arc strike. A discontinuity consisting of any localized remelted metal, heat-affected metal, or change in the surface profile of any part of a weld or base metal resulting from an arc.
golpe del arco. Una discontinuidad que consiste de cualquier rederretimiento del metal localizado, metal afectado por el calor, o cambio en el perfil de la superficie de cualquier parte de la soldadura o metal base resultante de un arco.

arc time. The time during which an arc is maintained in making an arc weld.
tiempo del arco. El tiempo durante el que el arco se mantiene al hacer una soldadura de arco.

arc voltage. The voltage across the welding arc.
voltaje del arco. El voltaje a través del arco de soldar.

arc welding (AW). A group of welding processes producing coalescence of workpieces by melting them with an arc. The

processes are used with or without the application of pressure and with or without filler metal.
soldadura de arco (AW). Un grupo de procesos de soldadura que producen una unión de piezas de trabajo calentándolas con un arco. Los procesos se usan con o sin la aplicación de presión y con o sin metal para rellenar.

arc welding deposition efficiency. The ratio of the weight of filler metal deposited in the weld metal to the weight of filler metal melted, expressed in percent.
eficiencia de deposición de soldadura de arco. La relación del peso del metal depositado en la soldadura al peso del metal para rellenar, y el metal derretido, expresado en por ciento.

arc welding electrode. A component of the welding circuit through which current is conducted between the electrode holder and the arc. See also arc welding (AW).
electrodo para soldadura de arco. Un componente del circuito de soldadura que conduce la corriente a través del porta-electrodo y el arco. Vea también soldadura de arco.

arc welding gun. A device used to transfer current to a continuously fed consumable electrode, guide the electrode, and direct the shielding gas.
pistola de soldadura de arco. Aparato que se usa para transferir corriente eléctrica continuamente a un alimentador de electrodo consumible. También se usa para guiar al electrodo y dirigir el gas de protección.

***arm.** An interconnected set of links and powered joints comprising a manipulator, which supports or moves a wrist and hand or end effector.
brazo. Una entreconexión que une un juego de eslabones y coyunturas de potencia conteniendo un manipulador, que apolla o mueve una muñeca o mano o el que efectúa al final.

as-welded. Pertaining to the condition of weldments prior to subsequent thermal, mechanical, or chemical treatments.
como-soldado. Pertenece a metal soldado, juntas soldadas, o soldaduras ya soldadas pero antes de que se les hagan tratamientos termales, mecánicos, o químicos.

***atmospheric pressure.** The pressure at sea level resulting from the weight of a column of air on a specified area; expressed for an area of 1 sq in. or sq cm; normally given as 14.7 psi (1.05 kg/cm^2).
presion atmosferica. La presión al nivel del mar que resulta del peso de una columna de aire en una area especificada; expresada para una área de 1 pulgada cuadrada o un centímetro cuadrado. Normalmente dado como 14.7 psi (1.05 kg/cm^2).

***atomic hydrogen.** A single free, unbounded hydrogen atom (H) usually formed when molecular hydrogen is exposed to an arc.
hidrógeno atómico. Un solo átomo de hidrógeno (H) libre, que normalmente se forma cuando se expone hidrógeno molecular a un arco.

atomic hydrogen welding (AHW). An arc welding process that uses an arc between two metal electrodes in a shielding atmosphere of hydrogen and without the application of pressure. This is an obsolete or seldom-used process.
soldadura atómica hidrógena (AHW). Un proceso de soldadura de arco que usa un arco entre dos electrodos de metal en una atmósfera de protección de hidrógeno y sin la aplicación de presión. Esto es un proceso anticuado y es rara la vez que se use.

***atoms.** Smallest particle of matter that still contains the properties of that matter.
átomos. Las partículas más pequeñas de materia que aún mantienen las propiedades de dicha materia.

***austenite.** A nonmagnetic course micro structured crystalline form of some iron and iron-carbon alloys that form as the result of the rate of cooling.
austenita. Forma no magnética de microestructura cristalina de algunos tipos de hierro y aleaciones de hierro y carbono que se forma como resultado del índice de enfriamiento.

***austenitic manganese steel.** A steel alloy with a high carbon content containing 10% or more manganese that is very tough and that will harden when cold worked.
acero al manganeso austenítico. Aleación de acero con un alto contenido de carbono, que contiene un 10% o más de manganeso, y que es muy tenaz y endurece cuando se lo trabaja en frío.

autogenous weld. A fusion weld made without filler metal.
soldadura autógena. Una soldadura fundida sin metal de rellenar.

***automated operation.** Welding operations performed repeatedly by a robot or another machine that is programmed to perform a variety of processes.
operación automatizada. Operaciones de soldaduras que se ejecutan repetidamente por un robot u otra maquina que está programada para hacer una variedad de procesos.

***automatic arc welding downslope time.** The time during which the current is changed continuously from final taper current or welding current to final current.
tiempo del pendiente con descenso en soldadura de arco automático. El tiempo durante en que la corriente cambia continuamente disminuyendo la corriente final o la corriente de la soldadura a la corriente final.

***automatic arc welding upslope time.** The time during which the current changes continuously from the initial current to the welding current.
tiempo de pendiente con ascenso en soldadura de arco automático. El tiempo durante en que la corriente cambia continuamente de donde se inició la corriente a la corriente de la soldadura.

***automatic operation.** Welding operations performed repeatedly by a machine that has been programmed to do an entire operation without the interaction of the operator.
operación automática. Operaciones de soldadura que se ejecutan repetidamente por una maquina que ha sido programada para hacer una operación entera sin influencia del operador.

***automatic oxygen cutting.** Oxygen cutting with equipment that performs the cutting operation without constant observation and the adjustment of the controls by an operator. The equipment may or may not perform loading and unloading of the work.
corte del oxígeno automático. Cortadura del oxígeno con equipo que hace la operación de cortar sin observación y ajuste de los controles por el operador. El equipo puede que ejecute o no el trabajo de cargar o descargar las piezas.

***automatic welding.** Welding with equipment that requires only occasional or no observation of the welding and no manual adjustment of the equipment controls. Variations of this term are

automatic brazing, automatic soldering, automatic thermal cutting, and *automatic thermal spraying.*

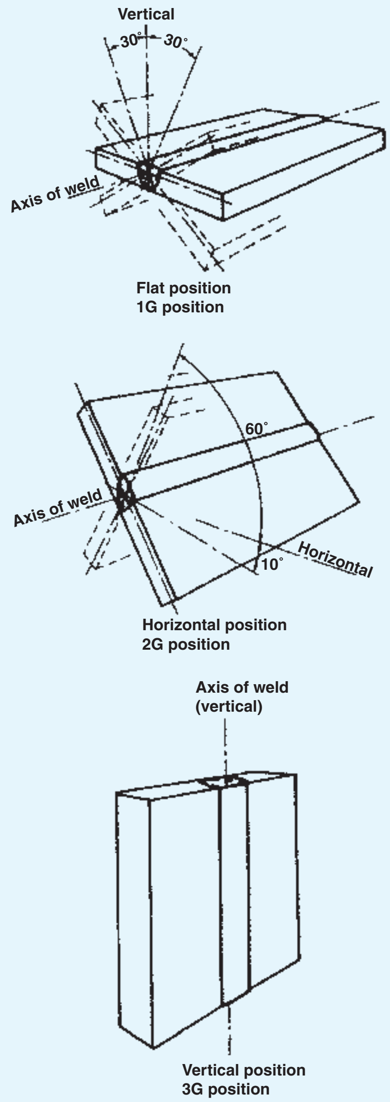
soldadura automática. Soldadura con equipos que requieren ocasional o ninguna observación, y ningun ajuste manual de los controles de los equipos. Variaciones de éste término son *soldadura fuerte automática, soldadura automática, corte termal automático, rociadura termal automático.*

***axial spray metal transfer.** Method of metal transfer used by GMAW and FCAW processes. See spray transfer.

traslado del metál por rociado axial. Método de transferencia de metal usado en los procesos GMAW y FCAW. Ver traslado rociado.

axis of a weld. A line through the length of a weld, perpendicular to and at the geometric center of its cross section.

eje de la soldadura. Una linea a lo largo de la soldadura perpendicula a y al centro geométrico de su corte transversal.



Positions of welding – groove welds

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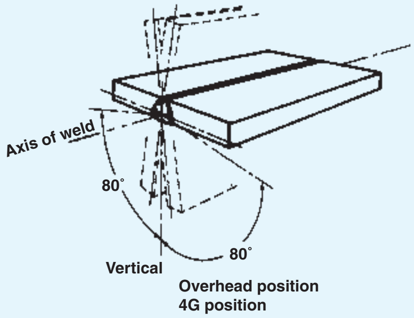
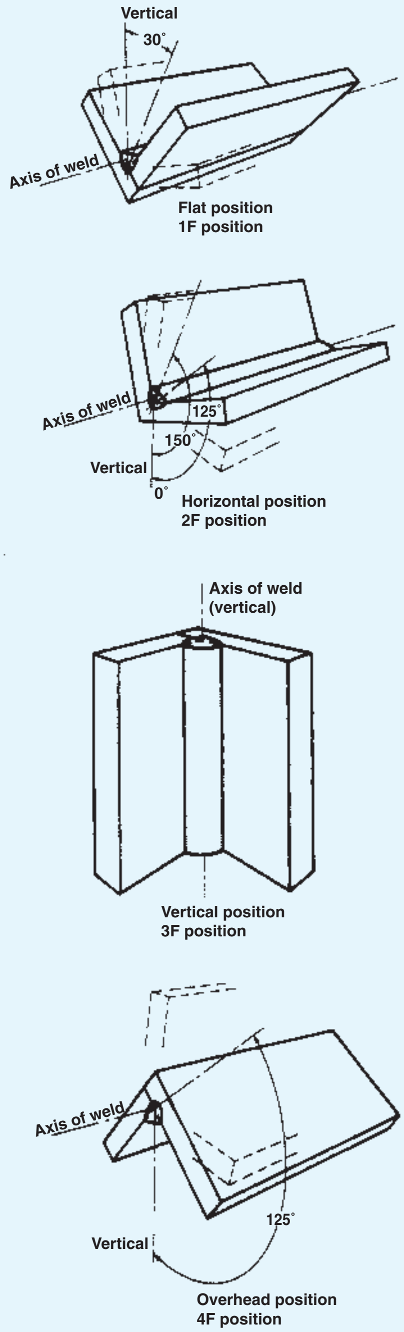


Positions of welding – groove welds



Positions of welding – fillet welds

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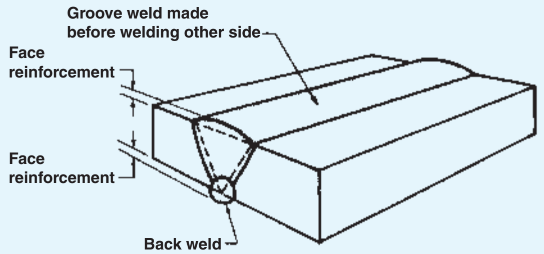
B

back gouging. The removal of weld metal and base metal from the weld root side of a welded joint to facilitate complete fusion and complete joint penetration upon subsequent welding from that side.
gubia trasera. Quitar el metal soldado y el metal base del lado de la raíz de una junta soldada para facilitar una fusión completa y penetración completa de la junta soldada subsecuente a soldar de ese lado.
back weld. A weld deposited at the back of a single groove weld.
soldadura de atrás. Una soldadura que se deposita en la parte de atrás de una soldadura de ranura sencilla.



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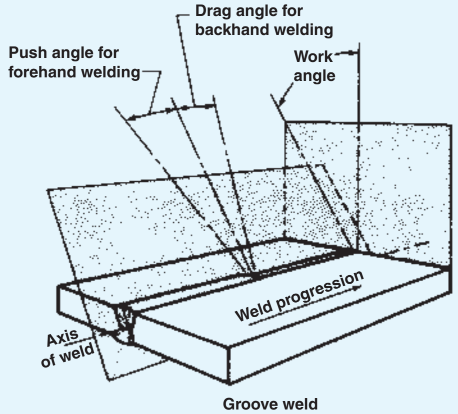
backfire. The momentary recession of the flame into the torch, potentially causing a flashback or sustained backfire. It is usually signaled by a popping sound after which the flame may either extinguish or reignite at the end of the tip.
llama de retroceso. El retroceso momentaneo de la llama dentro de la punta para soldar, punta para cortar, o pistola para rociar con llama. La llama puede reaparecer inmediatamente o apagarse completamente.

backhand welding. A welding technique in which the welding torch or gun is directed opposite to the progress of welding. Sometimes referred to as the "pull gun technique" in GMAW and FCAW. See also travel angle, work angle, and drag angle.
soldadura en revés. Una técnica de soldar la cual el soplete o pistola es guiada en la dirección contraria al adelantamiento de la soldadura. A veces se refiere como una tecnica de "estirar la pistola" en GMAW y FCAW. Vea también ángulo de avance, ángulo de trabajo, y ángulo del tiro.



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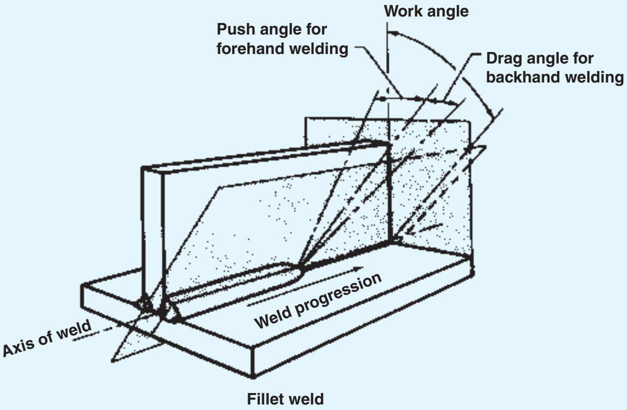

Position of electrode or torch
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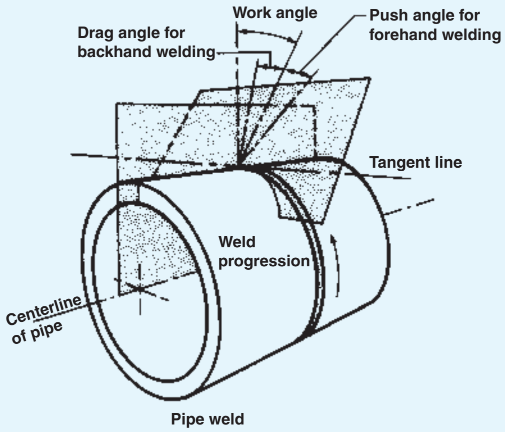

Position of electrode or torch
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backing. A material (base metal, weld metal, carbon, or granular material) placed at the root of a weld joint for the purpose of supporting molten weld metal.
respaldo. Un material (metal base, metal de soldadura, carbón o material granulado) puesto en la raíz de la junta soldada con el proposito de sostener el metal de la soldadura que está derretido.

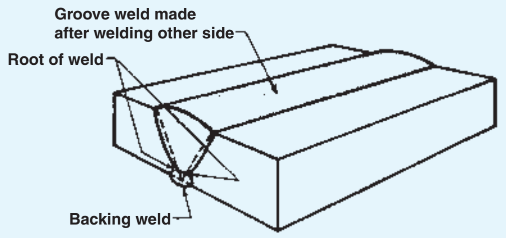
***backing gas.** A gas provided to protect the root of a weld from atmospheric contamination.
***gas de respaldo.** Gas proporcionado para proteger la raíz de una soldadura de la contaminación atmosférica.

backing pass. A pass made to deposit a backing weld.
pasada de respaldo. Una pasada hecha para depositar la pasada del respaldo.

backing ring. Backing in the form of a ring, generally used in the welding of piping.
anillo o argolla de respaldo. Respaldo en forma de argolla, generalmente se usa en soldaduras de tubos.

backing strip. Backing in the form of a strip.
tira de respaldo. Un respaldo en la forma de una tira.

backing weld. Backing in the form of a weld.
soldadura de respaldo. Respaldo en la forma de soldadura.



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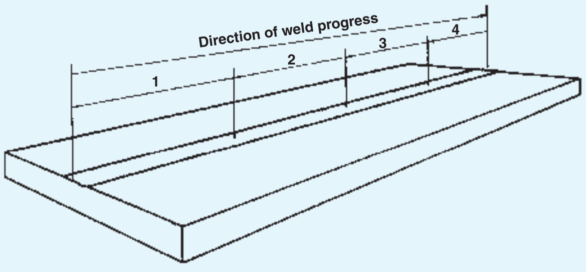
backstep sequence. A longitudinal sequence in which the weld bead increments are deposited in the direction opposite to the progress of welding the joint.
secuencia a la inversa. Una serie de soldaduras en secuencia longitudinal hechas en la dirección opuesta del progreso de la soldadura.



Backstep sequence
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bare electrode. A filler metal electrode that has been produced as a wire, strip, or bar with no coating or covering other than that which is incidental to its manufacture or preservation.
electrodo descubierto. Un electrodo de metal para rellenar que se ha producido como alambre, tira, o barra sin revestimiento o cubierto con solo lo necesario para su fabricación y conservación.

base material. The material that is welded, brazed, soldered, or cut. See also base metal and substrate.
material base. El material que está soldado, soldado con soldadura fuerte, soldado con soldadura blanda, o cortado. Vea también metal base y substrato.

base metal. The metal or alloy that is welded, brazed, soldered, or cut. See also base material and substrate.
metal base. El metal que está soldado con soldadura fuerte, soldado con soldadura blanda, o cortado. Vea también material base y substrato.

base metal test specimen. A test specimen composed wholly of base metal.
probeta para metal base. Una probeta totalmente compuesta de metal base.

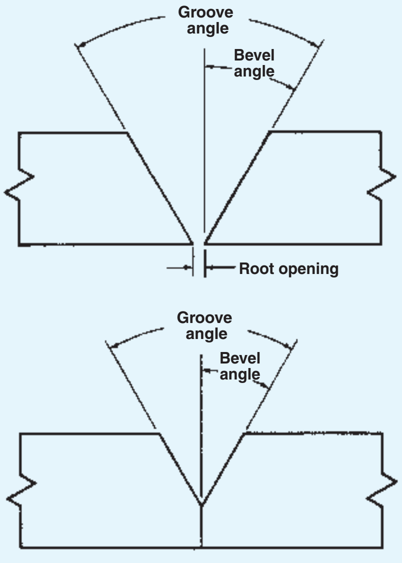
bend test. A test in which a specimen is bent to a specified bend radius. See also face-bend test, root-bend test, and side-bend test.
prueba de dobléz. Una prueba donde la probeta se dobla a una vuelta con un radio specificado. Vea también prueba de dobléz de cara, prueba de dobléz de raíz, y prueba de dobléz de lado.

bevel. An angular type of edge preparation.
bisel. Una preparación de tipo angular con filo.

bevel angle. The angle formed between the prepared edge of a member and a plane perpendicular to the surface of the member. Refer to drawings for bevel.
ángulo del bisel. El ángulo formado entre el corte preparado de un miembro y la plana perpendicular a la superficie del miembro. Refiera a los dibujos del bisel.

***bill of materials.** A document that lists all of the material required to construct a project. It may or may not contain the prices.
***lista de materiales.** Documento que lista todos los materiales requeridos para construir un proyecto. Puede o no contener los precios.

***bird nesting.** A ball of tangled wire that results when welding wire gets stuck in the gun liner and the feeder keeps feeding on either GMA or FCA welding.
***nido de ave.** En las soldaduras GMA o FCA, bola de alambres entrelazados que se produce cuando el alambre de la soldadura se queda atorado en la pistola y el alimentador continúa suministrando más alambre.



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blind joint. A joint, no portion of which is visible.
junta ciega. Una junta en que no hay porción visible.

block sequence. A combined longitudinal and cross-sectional sequence for a continuous multiple pass weld in which separated segments are completely or partially welded before intervening segments are welded.
secuencia de bloques. Una soldadura continua de pasadas multiples en sucesión combinadas longitudinal y sección transversa donde los incrementos separados son completamente o parcialmente soldados antes que los incrementos sean soldados.

***body-centered cubic (BCC).** A crystalline structure called ferrite that iron forms as it changes from a liquid to a solid. See also crystalline structures.
***red cúbica centrada en las caras (BCC).** Estructura cristalina llamada ferrita que el hierro forma a medida que cambia de líquido a sólido. Ver también estructura espacial cristalina.

bonding force. The force that holds two atoms together; it results from a decrease in energy as two atoms are brought closer to one another.
fuerza ligamentosa. La fuerza que detiene dos átomos juntos; es el resultado del decrecimiento en la energía cuando dos átomos son traídos cerca del uno al otro.

braze. A bond produced as a result of heating an assembly to the brazing temperature, 840°F (450°C), using a brazing filler metal distributed and retained between the closely fitted faying surfaces of the joint by capillary action.
soldadura de latón. Una soldadura producida cuando se calienta un montaje a una temperatura conveniente usando un metal de relleno que se liquida arriba de 840°F (450°C) y abajo del estado sólido del metal base. El metal de relleno es distribuido por acción capilar en una junta entre las superficies empalmadas montadas muy cerca.

***braze buildup.** Braze metal added to the surface of a part to repair wear.
formación con bronce. Reparación de partes gastadas donde se agrega bronce.

braze metal. That portion of a braze that has been melted during brazing.
latón. La porción del bronce que se derrite cuando se solda.

braze welding. A welding process variation that uses a filler metal with a liquidus above 840°F (450°C) and below the solidus of the base metal. Unlike brazing, in braze welding the filler metal is not distributed in the joint by capillary action.
soldadura con bronce. Es un proceso de soldar variante que usa un metal de relleno con un liquido arriba de 840°F (450°C) y abajo del estado del metal base. Distinto a la soldadura fuerte, el metal de relleno no es distribuido por acción capilar.

brazeability. The capacity of a material to be brazed under the imposed fabrication conditions into a specific, suitably designed structure capable of performing satisfactorily in the intended service.
soldabilidad fuerte. La capacidad de un metal de refuerzo bajo las condiciones impuestas en la fabricación de una estructura diseñada especificamente para funcionar satisfactoriamente en los servicios intentados.

brazement. An assembly whose component parts are joined by brazing.
montaje de soldadura fuerte. Un montaje donde las partes son unidas por soldadura fuerte.

brazing (B). A group of welding processes that produces coalescence of materials by heating them to the brazing temperature in the presence of a filler metal with a liquidus above 840°F (450°C) and below the solidus of the base metal. The filler metal is distributed between the closely fitted faying surfaces of the joint by capillary action.
soldadura fuerte (B). Un grupo de procesos de soldadura que produce coalescencia de materiales calentándolos a una temperatura de soldar en la presencia de un material de relleno el cual se derrite a una temperatura de 840°F (450°C) y bajo del estado sólido del metal base. El metal de relleno se distribuye por acción capilar de una junta entre las superficies empalmadas montadas muy cerca.

***brazing alloys.** A nonstandard term for brazing filler metal.
***aleaciones para soldadura fuerte.** Término no estandarizado de metal de relleno para soldadura fuerte.

brazing filler metal. The metal or alloy to be added in making a brazed joint. The filler metal has a liquidus above 840°F (450°C) but below the solidus of the base material.
metal de relleno para soldadura fuerte. El metal que rellena el espacio libre en la junta capilar y se derrite a una temperatura de 840°F (450°C) y bajo del estado sólido del metal base.

brazing procedure qualification record (BPQR). A record of brazing variables used to produce an acceptable test brazement and the results of tests conducted on the brazement to qualify a brazing procedure specification.
registro del procedimiento de calificación de la soldadura fuerte (BPQR). Un registro de variables de la soldadura fuerte que se usan para producir una probeta bronceada aceptable y los resultados de la prueba conducidas en el bronceamiento para calificar la especificación del procedimiento de la soldadura fuerte.

brazing procedure specification (BPS). A document specifying the required brazing variables for a specific application.
especificación del procedimiento de la soldadura fuerte (BPS). Un documento especificando los variables requeridos de la soldadura fuerte para una aplicación especificada.

brazing rod. Filler metal used in the brazing process is supplied in the form of rods; the filler metal is usually an alloy of two or more metals; the percentages and types of metals used in the alloy impart different characteristics to the braze being made. Several classification systems are in use by manufacturers of filler metals. See also brazing filler metal.
varilla de latón. Metal de relleno usado en procesos de soldadura fuerte es surtida en forma de varillas; el metal para rellenar es usualmente un aleación de dos o más metales; los porcentajes y tipos de metales usados en la aleación imparten diferentes características a la soldadura que se está haciendo. Varios sistemás de clasificación se están usando por los fabricantes de metales de relleno. Vea también metal de relleno para soldadura fuerte.

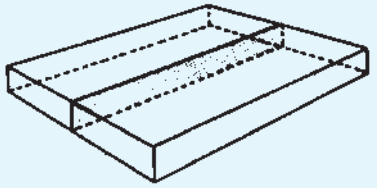
brazing temperature. The temperature to which the base metal is heated to enable the filler metal to wet the base metal and form a brazed joint.
temperatura de soldadura fuerte. La temperatura a la cual se calienta el metal base para permitir que el metal de relleno moje al metal base y forme la soldadura fuerte.

buildup. The material deposited by the welding filler metal to a weld. Also, surfacing variation in which surfacing material is deposited to achieve the required dimensions. See also buttering, cladding, and hardfacing.
recubrimiento. La materia depositada por el metal de masilla de soldadura a una soldadura. También, una variación en la superficie donde el metal es depositado para que pueda obtener las dimensiones requeridas. Vea también recubrimiento antes de terminar una soldadura, capa de revestimiento, y endurecimiento de caras.

***buried arc transfer.** In gas metal arc welding, a method of transfer in which the wire tip is driven below the surface of the weld pool due to the force of the carbon dioxide shielding gas. The shorter arc reduces the size of the drop, and any spatter is trapped in the cavity produced by the arc.
traslado de arco enterrado. En soldaduras de arco metalico con gas, un método de transferir en la cual la punta del alambre es enterrado debajo de la superficie del metal derretido debido a la fuerza del carbón bióxido del gas protector. Lo corto del arco reduce el tamaño de la gota y la salpicadura es atrapada en el hueco producido por el arc.

burnthrough. A hole or depression in the root bead of a single-groove weld due to excessive penetration. A nonstandard term when used for melt-through.
metal quemado que pasa al otro lado. Metal derretido que se quema en el lado de atrás del plato.

butt joint. A joint between two members aligned approximately in the same plane.
junta a tope. Una junta entre dos miembros alineados aproximadamente en el mismo plano.



Butt joint

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buttering. A surfacing variation depositing surfacing metal on one or more surfaces to provide metallurgically compatible weld metal for the subsequent completion of the weld.
recubrimiento antes de terminar una soldadura. Una variación de la superficie donde se deposita una o más capas de metal soldado en la ranura de un miembro (por ejemplo, un deposito de soldadura de aleación alta en un metal base de acero la cual será soldada a un metal base diferente). El recubrimiento proporciona una transición conveniente a la soldadura depositada para el acabamiento subsiguiente de una junta tope.

C

capillary action. The force by which liquid, in contact with a solid, is distributed between closely fitted faying surfaces of the joint to be brazed or soldered.
acción capilar. La fuerza por la que el liquido, en contacto con un sólido, es distribuido entre el empalme de las juntas del superficie para soldadura fuerte o blanda.

***carbon.** A nonmetallic element that can be found in all organic and many inorganic compounds, the most common allowing element used in iron to change its mechanical properties.
***carbón.** Elemento no metálico que está presente en todos los compuestos orgánicos y en muchos compuestos inorgánicos; elemento adicional más comúnmente usado con el hierro para cambiarle sus propiedades mecánicas.

carbon arc cutting (CAC). An arc cutting process that uses a carbon electrode. See also air carbon arc cutting.
corte con arco y carbón (CAC). Un proceso de corte con arco que usa un electrodo de carbón. Vea también arco de carbón con aire.

carbon arc gouging (CAG). A thermal gouging process using heat from a carbon arc and the force of compressed air or other nonflammable gas.
gubiadura con arco de carbón (CAG). Proceso de gubiadura térmica que utiliza el calor del arco de carbón y la fuerza del aire comprimido u otro gas no inflamable.

carbon arc welding (CAW). An arc welding process that uses an arc between a carbon electrode and the weld pool. The process is used with or without shielding and without the application of pressure.
soldadura con arco de carbón (CAW). Un proceso de soldar de arco en que se usa un arco entre el electrodo de carbón y el metal derretido. El proceso se usa con o sin protección y sin aplicación de presión.

carbon electrode. A nonfiller metal electrode used in arc welding and cutting, consisting of a carbon or graphite rod, which may be coated with copper or other materials.
electrodo de carbón. Un electrodo de metal que no se rellena usado en soldaduras de arco y para cortes consistiendo de varillas de carbón o grafito que pueden ser cubiertas de cobre u otros materiales.

***carbon steel.** Steel whose physical properties are primarily the result of the percentage of carbon contained within the alloy. Carbon content ranges from 0.04% to 1.4%, often referred to as *plain carbon steel, low-carbon steel*, or *straight carbon steel*.
acero al carbono. Acero cuyas propiedades físicas son primariamente el resultado del porcentaje de carbón que es contenido dentro de la aleación. El contenido del carbón es clasificado entre 0.04% a 1.4%, frecuentemente es referido *como el carbono de acero liso, acero de bajo carbón*, o *carbon de acero recto.*

carbonizing (carburizing). A reducing oxyfuel gas flame in which there is an excess of fuel gas, resulting in a carbon-rich zone extending around and beyond the cone.
llama carburante. Una llama minorada de gas combustible a oxígeno donde hay un exceso de gas combustible, resultando en una zona rica de carboón extendiendose alrededor y al otro lado del cono.

***cast.** The natural curve in the electrode wire for gas metal arc welding as it is removed from the spool; cast is measured by the diameter of the circle that the wire makes when it is placed on a flat surface without any restraint.
distancia. La curva natural en el alambre electrodo para soldadura de arco metálico para gas cuando se aparta del carrete; la distancia es medida en el círculo que hace el alambre cuando es puesto en una superficie plana sin restricción.

***cast iron.** A combination of iron and carbon. The carbon may range from 2% to 4%. Approximately 0.8% of the carbon is combined with the iron. The remaining free carbon is found as graphite mixed throughout the metal. Gray cast iron is the most common form of cast iron.
acero vaciado. Una combinación de acero y carbono. El carbono puede ser clasificado de 2% a 4%. Aproximadamente 0.8% del carbono es combinado con el hierro. El resto de carbono libre es encontrado como grafito mezclado por todo el metal. El acero fundido gris es la forma más común.

cathode. A natural curve material with an excess of electrons, thus having a negative charge.
cátodo. Un material de curva natural con un exceso de electrones, por eso tiene una carga negativa.

***cell.** A manufacturing unit consisting of two or more workstations and the material transport mechanisms and storage buffers that interconnect them.
celda. Una unidad manufacturera la cual consiste de dos o más estaciones de trabajo y mecanismos para trasladar el material y los amortiguadores del almacén que los entreconecta.

cellulose-based electrode fluxes. Fluxes that use an organic-based cellulose ($C_6H_{10}O_5$) (a material commonly used to make paper) held together with a lime binder. When this flux is exposed to the heat of the arc, it burns and forms a rapidly expanding gaseous cloud of CO_2 that protects the molten weld

pool from oxidation. Most of the fluxing material is burned, and little slag is deposited on the weld. E6010 is an example of an electrode that uses this type of flux.
fundentes para electrodos celulósicos. Fundentes que usan celulosa de base orgánica ($C_6H_{10}O_5$) (un material normalmente utilizado para fabricar papel), y que se mantienen unidos con un aglomerante de cal. Cuando a este fundente se lo expone al calor del arco, se consume y forma una nube gaseosa de CO_2 que se expande rápidamente y protege de la oxidación al charco de soldadura derretido. La mayor parte del material del fundente se consume, y se deposita poca escoria en la soldadura. El E6010 es un ejemplo de un electrodo que utiliza este tipo de fundente.

***cementite.** A crystalline form of iron and carbon that is hard and brittle.
***cementita.** Forma cristalina del hierro y del carbón que es dura y quebradiza.

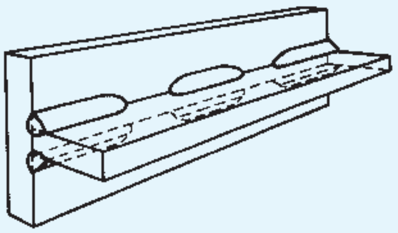
***center.** A manufacturing unit consisting of two or more cells and the materials transport and storage buffers that interconnect them.
centro. Una unidad manufacturera la cual consiste de dos o más celdas y el traslado de materiales y los amortiguadores del almacén que los entreconecta.

***centerline.** Lines on a drawing that show the center point of circles and arcs and round or symmetrical objects. They also locate the center point for holes, irregular curves, and bolts.
***línea central.** Líneas de un dibujo que muestran el punto central de círculos y arcos y de objetos redondos o simétricos. También sirven para ubicar los puntos centrales de hoyos, curvas irregulares, y pernos.

***certification.** See certified welders.
***certificación.** Ver soldador certificados.

certified welders. Individuals who have demonstrated their welding skills for a process by passing a specific welding test.
soldador certificados. Personas que han demostrado, mediante una prueba específica de soldadura, su habilidad para soldar en un proceso.

chain intermittent welds. An intermittent weld on both sides of a joint in which the weld segments on one side are approximately opposite those on the other side.
soladura intermitente de cadena. Soldadura intermitente en los dos lados de una junta en cual los incrementos de soldadura están aproximadamente opuestos a los del otro lado.



Chain intermittent fillet weld

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***chill plate.** A large piece of metal used in welding to correct overheating.
plato desalentador. Una pieza de metal grande que se usa para corregir el sobrecalentamiento.

cladding. A relatively thick layer greater than 1 mm (0.04 in.) of material applied by surfacing for the purpose of improved corrosion resistance or other properties. See also coating, surfacing, and hardfacing.
capa de revestimiento. Una capa de material relativamente grueso superior a 1 mm (0.04 pulgadas) aplicada por la superficie con el objeto de mejorar la resistencia a la corrosión u otras propiedades. Vea también revestimiento, recubrimiento superficial, y endurecimiento de caras.

coalescence. The growing together or growth into one body of the materials being welded.
coelescencia. El crecimiento o desarrollo de un cuerpo de los materiales los cuales se están soldando.

coating. A relatively thin layer 1 mm (0.04 in.) of material applied by surfacing for the purpose of corrosion prevention, resistance to high-temperature scaling, wear resistance, lubrication, or other purposes. See also cladding, surfacing, and hardfacing.
revestimiento. Una capa de material relativamente delgado material de menos de 1 mm (0.04 pulgadas) aplicada por la superficie con el propósito de prevenir corrosión, resistencia a las altas temperaturas, resistencia a la deterioración, lubricación, o para otros propósitos. Vea también capa de revestimiento, recubrimiento superficial, y endurecimiento de caras.

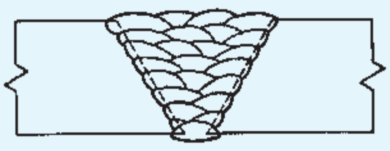
cold crack. A crack occuring in a metal at or near ambient temperatures. Cold cracks can occur in base metal, heat-affected zones, and weld metal zones.
quebradura en frío. Quebradura que ocurre en un metal a temperatura ambiente o a temperaturas cercanas a ésta. Las quebraduras en frío pueden ocurrir en base de metal, zonas afectadas por el calor y zonas de metal de soldadura.

cold soldered joint. A joint with incomplete coalescence caused by insufficient application of heat to the base metal during soldering.
junta soldada fría. Una junta con coalescencia incompleta causada por no haber aplicado suficiente calor al metal base durante la soldadura.

***combustion.** A rapid chemical reaction between oxygen and another substance that gives off heat and light.
combustión. Reacción química rápida entre el oxígeno y otra sustancia que emite calor y luz.

***combustion rate.** Also known as rate of propagation of a flame, this is the speed at which the fuel gas burns, in ft/sec (m/sec). The ratio of fuel gas to oxygen affects the rate of burning: a higher percentage of oxygen increases the burn rate.
velocidad de combustión. También es conocida como velocidad de propagación de una llama, ésta es la velocidad en la cual se quema el gas combustible, en pies/sec (m/sec). La proporción del gas combustible al oxígeno afecta la proporción de quemadura: un porcentaje más alto del oxígeno aumenta la proporción de quemarse.

complete fusion. Fusion over the entire fusion faces and between all adjoining weld beads.
fusión completa. Fusión sobre todas las caras de fusión y en medio de todos los cordónes de soldadura inmediatos.



Multiple pass groove weld.

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composite electrode (EC). A generic term for multicomponent filler metal electrodes in various physical forms, such as stranded wires, tubes, and covered wire. See also covered electrode, flux cored electrode, and stranded electrode.
electrodo compuesto (EC). Un término genérico para componentes múltiples para electrodos de metal de aporte en varias formas físicas, como cable de alambre, tubos, y alambre cubierto. Vea también electrodo cubierto, electrodo de núcleo de fundente, y electrodo cable.

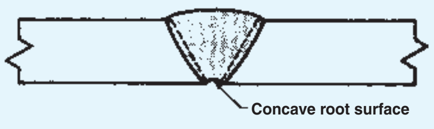
***computer-aided design (CAD).** Computer software programs that typically use vector lines to produce a mechanical type drawing.
***diseño asistido por computadora (CAD).** Programa de computadora que por lo general utiliza líneas vectoriales para producir un tipo mecánico de dibujo.

***computer-aided manufacturing (CAM).** Computer software programs used to aid in the automated manufacturing of parts.
***fabricación asistida por computadora (CAM).** Programa de computadora que se utiliza para asistir en la fabricación automatizada de piezas.

***computer control.** Control involving one or more electronic digital computers.
control de computadora. Un control que incluye una o más computadoras electrónicas dactilares.

concave fillet weld. A fillet weld with a concave face.
soldadura de filete cóncava. Soldadura de filete con cara cóncava.

concave root surface. A root surface that is concave.
superficie raíz cóncava. La superficie del cordón raíz con cara cóncava.



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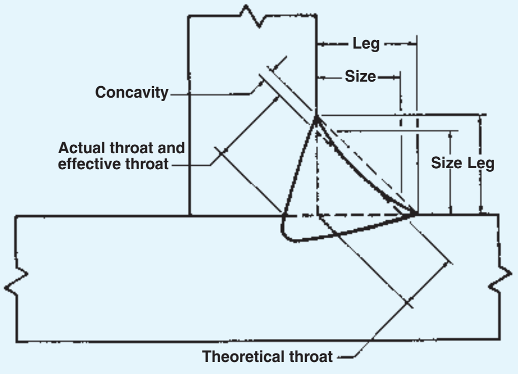
concavity. The maximum distance from the face of a concave fillet weld perpendicular to a line joining the toes.
concavidad. La distancia máxima de la cara de una soldadura de filete cóncava perpendicular a una linea que une con los pies.



Concave fillet weld

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conduit liner. A flexible steel tube that guides the welding wire from the feed rollers through the welding lead to the gun used for GMAW and FCAW welding. The steel conduit liner may have a nylon or Teflon inner surface for use with soft metals such as aluminum.
revestimiento de conducto. Un tubo flexible de acero que guía el alambre para soldar desde los rodillos de alimentación, a través de los cables para soldar, hasta la pistola, usado en soldaduras de tipo GMAW y FCAW. El revestimiento del conducto de acero puede tener una superficie interior de Teflon o nylon para su uso con metales blandos como el aluminio.

cone. The conical part of an oxyfuel gas flame adjacent to the orifice of the tip.
cono. La parte cónica de la llama del gas de oxígeno combustible que colinda con la abertura de la punta.

constricted arc. A plasma arc column shaped by the constricting orifice in the nozzle of the plasma arc torch or plasma spraying gun.
arco constreñido. Una columna de arco plasma que está formada por el constreñimiento del orificio en la lanza de la antorcha del arco plasma o pistola de rociado plasma.

constricting nozzle. A device at the exit end of a plasma arc torch or plasma spraying gun containing the constricting orifice.
boquilla de constreñimiento. Un aparato a la salida de la antorcha de un arco plasma o la pistola de rociado plasma que contiene la boquilla de constreñimiento.

constricting orifice. The hole in the constricting nozzle of the plasma arc torch or plasma spraying gun through which the arc plasma passes.
orificio de constreñimiento. El agujero en la boquilla del constreñimiento en la antorcha de arco plasma o de la pistola de rociado plasma por donde pasa el arco de plasma.

consumable electrode. An electrode that provides filler metal.
electrodo consumible. Un electrodo que surte el metal de relleno.

consumable insert. Filler metal placed at the joint root before welding and intended to be completely fused into the root of the joint and become part of the weld.
inserción consumible. Metal de relleno antepuesto que se funde completamente en la raíz de la junta y se hace parte de la soldadura.

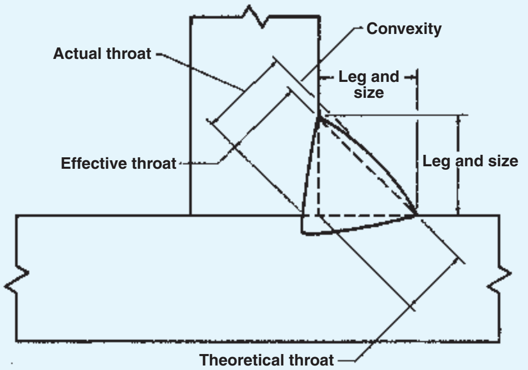
contact tube. A device that transfers current to a continuous electrode.
tubo de contacto. Un aparato que traslada corriente continua a un electrodo.

***contamination.** Any undesirable material that might enter the molten weld metal.
***contaminación.** Cualquier material no deseado que pueda ingresar dentro del metal de soldadura derretido.

continuous weld. A weld that extends continuously from one end of a joint to the other. Where the joint is essentially circular, it extends completely around the joint.
soldadura continua. Una soldadura que se extiende continuamente de una punta de la junta a la otra. Donde la junta es esencialmente circular, se extiende completamente alrededor de la junta.

convex fillet weld. A fillet weld with a convex face.
soldadura de filete convexa. Una soldadura de filete con una cara convexa.

convexity. The maximum distance from the face of a convex fillet weld perpendicular to a line joining the toes.
convexidad. La distancia máxima de la cara de la soldadura convexa filete perpendicula a la linea que une los pies.



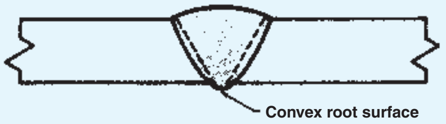
Convex fillet weld

American Welding Society

convex root surface. A root surface that is convex.
raíz superficie convexa. La raíz que es convexa.

copper. A pinkish or peach colored highly thermally and electrically conductive soft metal that resists corrosion.
cobre. Metal blando de color rosado o aduraznado resistente a la corrosión que es buen conductor del calor y de la electricidad.

copper alloys. An alloy primarily containing copper. The two most common copper alloys are brass, a copper tin alloy; and bronze, a copper zinc alloy.
aleación de cobre. Aleación que contiene principalmente cobre. Los dos tipos más comunes de aleaciones de cobre son el latón, un tipo de aleación de cobre y estaño; y el bronce, una aleación de cobre y zinc.



Melt through

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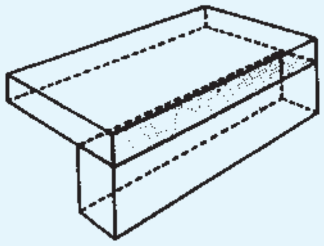
***core wire.** The wire portion of the coated electrode for shielded metal arc welding. The wire carries the welding current and adds most of the filler metal required in the finished weld. The composition of the core wire depends upon the metals to be welded.
alambre del centro. La porción del alambre del electrodo forrado para proteger el metal de la soldadura de arco. El alambre lleva la corriente de la soldadura y añade casi todo el metal para rellenar que es requerido para terminar la soldadura. La composición del alambre del centro depende de los metales que se van a usar para soldar.

cored solder. A solder wire or bar containing flux as a core.
soldadura de núcleo. Un alambre o barra para soldar que contiene fundente en el núcleo.

corner joint. A joint type in which butting or nonbutting ends of one or more workpieces converge approximately perpendicular to one another.
junta de esquina. Una junta dentro de dos miembros localizados aproximadamente a ángulos rectos de unos a otros.



Applicable welds

Fillet	Flare Bevel-Groove
Square-Groove	Edge-Flange
V-Groove	Corner-Flange
Bevel-Groove	Spot
U-Groove	Projection
J-Groove	Seam
Flare V-Groove	Braze

Corner joint

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***corrosion resistance.** The ability of the joint to withstand chemical attack; determined by the compatibility of the base materials to the filler metal.
resistencia a la corrosión. La abilidad de una junta de resistir ataques químicos; determinado por la compatibilidad de los materiales bases al metal de relleno.

corrosive flux. A flux with a residue that chemically attacks the base metal. It may be composed of inorganic salts and acids, organic salts and acids, or activated rosins or resins.
fundente corrosivo. Un fundente con un residuo que ataca químicamente al metal base. Puede estar compuesto de sales y ácidos inorgánicos, sales y ácidos orgánicos, o abelinotes o resinas activados.

cosmetic pass. A weld pass made primarily to enhance appearance.
pasada cosmética. Una pasada que se le hace a la soldadura para mejorar la apariencia.

***coupling distance.** The distance to be maintained between the inner cones of the cutting flame and the surface of the metal being cut, in the range of 1/8 in. (3 mm) to 3/8 in. (10 mm).
distancia de acoplamiento. La distancia que debe mantenerse entre los conos internos de la llama y la superficie del metal que se está cortando, varía de 1/8 pulgadas (3 mm) a 3/8 pulgadas (10 mm).

cover lens. A round cover plate.
lente para cubrir. Un plato redondo de vidrio para cubrir el lente obscuro.

***cover pass.** The last layer of weld beads on a multipass weld. The final bead should be uniform in width and reinforcement, not excessively wide, and free of any visual defects.
pasada para cubrir. La última capa de cordónes soldadura de pasadas múltiples. La pasada final debe ser uniforme en anchura y refuerzo, no excesivamente ancha, y libre de defectos visuales.

cover plate. A removable pane of colorless glass, plastic-coated glass, or plastic that covers the filter plate and protects it from weld spatter, pitting, and scratching.

plato para cubrir. Una hoja removible de vidrio claro, vidrio cubierto con plástico o plástico que cubre el plato filtrado y lo protege de salpicadura, picaduras y de que se rayen.

covered electrode. A composite filler metal electrode consisting of a bare or metal cored electrode with a flux covering to provide a slag layer and/or alloying elements. The covering may contain materials providing such functions as shielding from the atmosphere, deoxidation, and arc stabilization and can serve as a source of metallic additions to the weld.
electrodo cubierto. Un electrodo compuesto de metal para rellenar que consiste de un núcleo de un electrodo liso o electrodo con núcleo de metal el cual se le agrega cubrimiento suficiente para proveer una capa de escoria sobre el metal de la soldadura que se le aplicó. El cubierto puede contener materiales que pueden proveer funciones como protección de la atmósfera, deoxidación, y estabilización del arco, y también puede servir como fuente para añadir metales adicionales a la soldadura.

crack. A fracture-type discontinuity characterized by a sharp tip and high ratio of length and width to opening displacement.
grieta. Una desunión discontinuidada de tipo fractura caracterizada por una punta filoza y proporción alta de lo largo y de lo ancho al desplazamiento de la abertura.

crater. A depression in the weld face at the termination of a weld bead.
crater. Una depresión en la superficie de la soldadura a donde se termina el cordón de soldadura.

crater crack. A crack initiated and localized within a crater.
grieta de crater. Una grieta en el crater del cordón de soldar.

***creep.** A property of metal that allows it to be deformed under a load that is below the metal's yield point.
fluencia. Propiedad de los metales que permite su deformación bajo una carga menor al punto de deformación.

crevice corrosion. Oxidation that occurs in the small space (crevice) between two pieces of metal as the result of moisture being trapped in the small space.
corrosión de grieta. Oxidación que ocurre en espacios pequeños (grietas) entre dos piezas de metal como resultado de que la humedad quedara atrapada en el espacio pequeño.

critical weld. A weld so important to the soundness of the weldment that its failure could result in the loss or destruction of the weldment and injury or death.
soldadura crítica. Una soldadura tan importante para la calidad del conjunto de partes soldadas, que su fracaso podría ocasionar la pérdida o destrucción de dicho conjunto, así como también lesiones o muerte.

cross-sectional sequence. The order in which the weld passes of a multiple pass weld are made with respect to the cross section of the weld. See also block sequence.
secuencia del corte transversal. La orden en la cual se hacen las pasadas de la soldadura en una soldadura de pasadas múltiples hechas al respecto al corte transversal de la soldadura. Vea también secuencia de bloque.

crucible. A high-temperature container that holds the thermite welding mixture as it begins its thermal reaction before the molten metal is released into the mold.
crisol. Recipiente de alta temperatura que contiene la mezcla de la soldadura con termita en el momento en que comienza su reacción térmica antes de que el metal fundido se vierta en el molde.

***crystal lattices.** See crystalline structures.
celosías cristalinas. Ver estructura espacial cristalina.

***crystalline structures.** Orderly arrangements of atoms in a solid in a specific geometric pattern; sometimes called *lattices*.
estructura espacial cristalina. Un arreglo metódico de átomos en un modelo geométrico preciso. A veces se llaman *celosías*.

cup. A nonstandard term for gas nozzle.
tazón. Un término que no es la norma para de boquilla de gas.

cutting attachment. A device for converting an oxyfuel gas welding torch into an oxygen cutting torch.
equipo para cortar. Un aparato para convertir una antorcha para soldar en una antorcha para cortar con oxígeno.

***cutting gas assist.** A nonreactive or exothermic gas jet directed on the metal to aid in laser cutting.
corte con asistencia de gas. Chorro de gas exotérmico no reactivo dirigido hacia el metal para asistir en cortes con láser.

cutting head. The part of a cutting machine in which a cutting torch or tip is incorporated.
cabeza de la antorcha para cortar. La parte de una maquina para cortar en donde una antorcha para cortar o una punta es incorporada.

***cutting plane line.** Lines on a drawing that represent an imaginary cut through the object. They are used to expose the details of internal parts that would not be shown clearly with hidden lines.
Línea del plano de corte. Líneas de un dibujo que representan un corte imaginario a través del objeto. Se usan para exponer los detalles de las piezas internas que no se verían claramente con líneas escondidas.

cutting tip. The part of an oxygen cutting torch from which the gases issue.
punta para cortar. Esa parte de la antorcha para cortar con oxígeno por donde salen los gases.

cutting tip, high speed. Designed to provide higher oxygen pressure, thus allowing the torch to travel faster.
punta para cortar a alta velocidad. Diseñada para proveer presión más alta de oxígeno, asi puede caminar la antorcha más rápidamente.

cutting torch. A device used for plasma arc cutting to control the position of the electrode, to transfer current to the arc, and to direct the flow of plasma and shielding gas.
antorcha para cortar. Un aparato que se usa para cortes de arco de plasma para el control de la posición del electrodo.

***cycle time.** The period of time from starting one machine operation to starting another (in a pattern of continuous repetition).
tiempo del ciclo. El período de tiempo de cuando se empieza la operación de una maquina y cuando se empieza otra (en una norma de repetición continua).

cylinder. A portable container used for transportation and storage of a compressed gas.
cilindro. Un recipiente portátil que se usa para transportar y guardar un gas comprimido.

cylinder manifold. A multiple header for interconnection of gas sources with distribution points.
conexión de cilindros múltiple. Una tuberia con conexiones múltiples que sirve como fuente de gas con puntos de distribución.

***cylinder pressure.** The pressure at which a gas is stored in approximately 2200 lb per square inch (psi), and acetylene is stored at approximately 225 psi.
presión del cilindro. La presión del cilindro en el cual un gas se guarda en aproximadamente 2200 libras por pulgada cuadrada (psi), y el acetilino se guarda a aproximadamente 225 psi.

D

defect. A discontinuity or discontinuities that by nature or accumulated effect (for example, total crack length) render a part or product unable to meet minimum applicable acceptance standards or specifications. This term designates rejectability and flaw. See also discontinuity and flaw.
defecto. Una desunión o desuniónes que por la naturaleza o efectos acumulados (por ejemplo, distancia total de una grieta) hace que una parte o producto no esté de acuerdo con las normas o especificaciones mínimas para aceptarse. Este término designado resectabilidad y falta. Vea también discontinuidad y falta.

defective weld. A weld containing one or more defects.
soldadura defectuosa. Una soldadura que contiene uno o más defectos.

***deoxidizers.** An element such as silicon that is added to a flux for the purpose of removing oxygen from the molten weld pool.
desoxidantes. Elemento como el silicio que se añade a un fundente con el propósito de extraer el oxígeno de la soldadura derretida.

deposited metal. Filler metal that has been added during a soldering, brazing, or welding operation.
metal depositado. Metal de relleno que se ha agregado durante una operación de soldadura.

deposition efficiency (arc welding). The ratio of the weight of deposited metal to the net weight of filler metal consumed, exclusive of stubs.
eficiencia de deposición (soldadura por arco). La relación del peso del metal depositado al peso neto del metal de relleno consumido, excluyendo los tacones.

deposition rate. The weight of material deposited in a unit of time. It is usually expressed as kilograms per hour (kg/hr) (pounds per hour [lb/h]).
relación de deposición. El peso del material depositado en una unidad de tiempo. Es regularmente expresado en kilogramos por hora (kg/hora) (libras por hora [lb/hora]).

depth of fusion. The distance that fusion extends into the base metal or previous bead from the surface melted during welding.
grueso de fusión. La distancia en que la fusión se extiende dentro del metal base o del cordón anterior de la superficie que se derretió durante la soldadura.

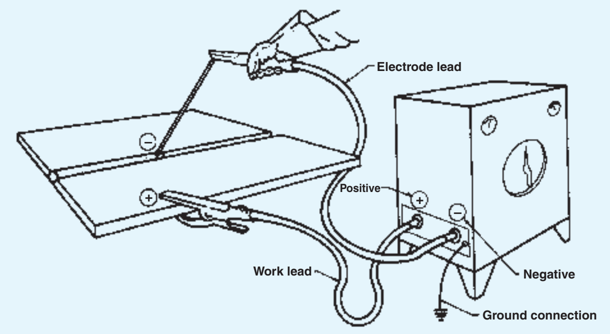
***destructive testing.** Mechanical testing of weld specimens to measure strength and other properties. The tests are made on specimens that duplicate the material and weld procedures required for the job.
prueba destructiva. Pruebas mecánicas de probetas de soldadura para medir la fuerza y otras propiedades. Las pruebas se hacen en probetas que duplican el material y los procedimientos de la soldadura requeridos para el trabajo.

***dimension line.** Lines on a drawing that are drawn so that their ends touch the object being measured, or they may touch the extension line extending from the object being measured.
línea de dimensión. Líneas de un dibujo que se trazan con el propósito de que sus extremos toquen el objeto que se mide. También pueden tocar la línea de extensión que se extiende desde el objeto que se mide.

***dimensioning.** The measurements of an object, such as its length, width, and height, or the measurements for locating such things as parts, holes, and surfaces.
acotación. Las medidas de un objeto, tal como su longitud, ancho, y altura, o las medidas para ubicar cosas como piezas, agujeros o superficies.

dip brazing (DB). A brazing process that uses heat from a molten salt bath or a metal. When using the molten salt bath may act as flux. When using the molten metal, the bath provides the filler metal.
soldadura fuerte por inmersión (DB). Es un proceso de soldadura fuerte que usa el calor de una sal fundida o un baño de metal. Cuando se usa la sal fundida el baño puede actuar como flujo. Cuando se usa el metal fundido, el baño proporciona el metal de relleno.

dip soldering (DS). A soldering process using the heat, oil, or salt bath in which it is immersed.
soldadura blanda de bajo punto de fusión por inmersión (DS). Un proceso que usa calor proporcionado por un baño de metal derretido que provee el metal de relleno para soldar.



Direct-current electrode negative (straight polarity)

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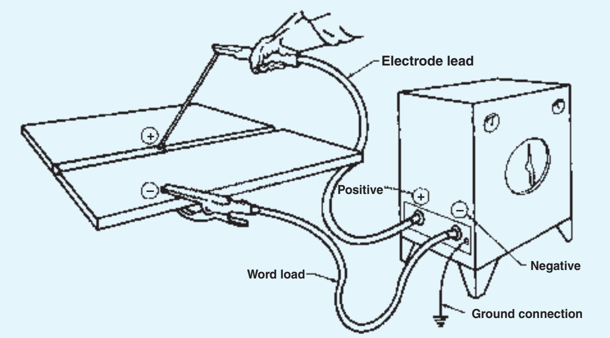
direct-current electrode negative (DCEN). The arrangement of direct-current arc welding leads on which the electrode is the negative pole and the workpiece is the positive pole of the welding arc.
corriente directa con electrodo negativo (DCEN). El arreglo de los cables para soldar con la soldadura de arco donde el electrodo es polo negativo y la pieza de trabajo es polo positivo de la soldadura de arco.



Direct-current electrode positive (reverse polarity)

American Welding Society

direct-current electrode positive (DCEP). The arrangement of direct-current arc welding leads on which the electrode is the positive pole and the workpiece is the negative pole of the welding arc.
corriente directa con el electrodo positivo (DCEP). El arreglo de los cables para soldar con la soldadura de arco con el electrodo es el polo positivo y la pieza de trabajo es el polo negativo de la soldadura de arco.

discontinuity. An interruption of the typical structure of a material, such as a lack of homogeneity in its mechanical, metallurgical, or physical characteristics. A discontinuity is not necessarily a defect. See also defect and flaw.
discontinuidad. Una interrupción de la estructura típica de un material, el que falta de homogenidad en sus caracteristicas mecánicas, metalúrgicas, o fisica. Vea también defecto y falta.

***distortion.** Movement or warping of parts being welded, from the prewelding position and condition compared to the postwelding condition and position.
deformacion. Movimiento o torcimiento de las partes que se están soldando, comparando la posición antes de soldar a la posicion despues de soldar.

double bevel-groove weld. A type of groove weld. Refer to drawing for groove weld.
soldadura de ranura con doble bisel. Es un tipo de soldadura de ranura. Refiérase al dibujo para soldadura de ranura.

double J-groove weld. A type of groove weld. Refer to drawing for groove weld.
soldadura de ranura de doble-J-. Un tipo de soldadura de ranura. Refiérase al dibujo para soldadura de ranura.

double U-groove weld. A type of groove weld. Refer to drawing for groove weld.
soldadura de ranura de doble-U-. Un tipo de soldadura de ranura. Refiérase al dibujo para soldadura de ranura.

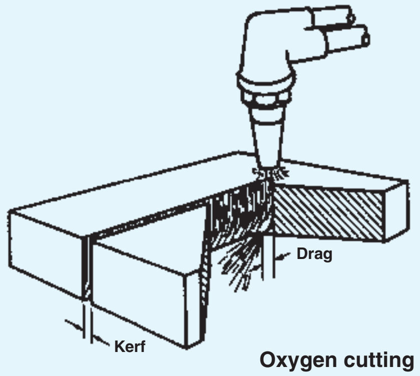
double V-groove weld. A type of groove weld. Refer to drawing for groove weld.
soldadura de ranura de doble-V-. Un tipo de soldadura de ranura. Refiérase al dibujo para soldadura de ranura.

double-flare bevel-groove weld. A type of groove weld. Refer to drawing for groove weld.
soldadura de ranura con doble bisel acampanada. Un tipo de soldadura de ranura. Refiérase al dibujo para soldadura de ranura.

double-flare V-groove weld. A weld in grooves formed by two members with curved surfaces. Refer to drawing for groove weld.
soldadura de ranura de doble V acampanada. Una soldadura de ranura formada por dos miembros con superficies curvados. Refiérase al dibujo para soldadura de ranura.

downslope time. See automatic arc welding downslope time and resistance welding downslope time.
tiempo de caída del pendiente. Vea tiempo del pendiente con descenso en soldadura de arco automático y tiempo del pendiente descenso en soldadura de resistencia.

drag (thermal cutting). The offset distance between the actual and straight-line exit points of the gas stream or cutting beam measured on the exit surface of the base metal.
tiro (corte termal). La distancia desalineada entre la actual y la linea recta del punto de salida del chorro de gas o el rayo de cortar medido a la salida de la superficie del metal base.



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drag angle. The travel angle when the electrode is pointing in a direction opposite to the progression of welding. This angle can also be used to partially define the position of guns, torches, rods, and beams.
ángulo del tiro. El ángulo de avance cuando el electrodo está apuntando en una dirección opuesta del progreso de la soldadura. Este ángulo también se puede usar para parcialmente definir la posición de pistolas, antorchas, varillas, y rayos.

***drag lines.** High-pressure oxygen flow during cutting forms lines on the cut faces. A correctly made cut has up and down drag lines (zero drag); any deviation from the pattern indicates a change in one of the variables affecting the cutting process; with experience the welder can interpret the drag lines to determine how to correct the cut by adjusting one or more variables.
lineas del tiro. La salida del oxígeno a presión elevada durante el corte forma lineas en las caras del corte. Un corte hecho correctamente tiene lineas hacia arriba y hacia abajo (zero tiro); cualquier desviación de la norma indica un cambio en uno de los variables que afectan el proceso de cortar; con experiencia el soldador puede interpretar las lineas de tiro y determinar como corregir el corte ajustando uno o más variables.

***drift.** The tendency of a system's response to gradually move away from the desired response.
deriva. La tendencia de la respuesta del sistema de retirarse gradualmente de la respuesta deseada.

***drooping output.** Volt-ampere characteristic of the shielded metal arc process power supply where the voltage output decreases as increasing current is required of the power supply. This characteristic provides a reasonably high voltage at a constant current.
reducción de potencia de salida. Característica de voltioamperios de la alimentación de poder de un proceso de soldadura de arco protegido donde la salida del voltaje disminuye mientras un aumento de la corriente es requerida de la alimentación de poder. Está característica proporciona un voltaje razonable alto con corriente constante.

***dross.** The material expelled from the plasma arc and oxygen assist laser cutting processes, which contains 40% or more of unoxidized base metal.
escoria. Material expelido en los procesos de corte de arco de plasma y de corte láser asistido con oxígeno que contiene 40% o más de base de metal no oxidada.

***dual shield.** FCA welding process that uses both the flux core and an external shielding gas to protect the molten weld pool. See self-shielding.
protección doble. Proceso de soldadura FCA que utiliza un fundente de núcleo y protección externa de gas para proteger la soldadura derretida. Ver autoprotección.

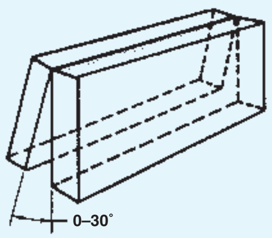
***ductility.** As applied to a soldered or brazed joint, it is the ability of the joint to bend without failing.
ductilidad. Como aplicada a junta de soldadura fuerte o soldadura blanda, es la abilidad de la junta de doblarse sin fallar.

duty cycle. The percentage of time during a specified test period that a power source or its accessories can be operated at rated output without overheating. The test periods for arc welding and resistance welding are ten (10) minutes and one (1) minute, respectively.
ciclo de trabajo. El porcentaje de tiempo durante un período a prueba arbitraria de una fuente de poder y sus accesorios que pueden operarse a la capacidad de carga de salida sin sobrecalentarse.

E

***eddy current inspection (ET).** See nondestructive testing.
inspección de corriente parásita (ET). Ver pruebas no destructivas.

edge joint. A joint type in which the nonbutting ends of one or more workpieces lie approximately parallel.
junta de orilla. Una junta en medio de las orillas de dos o más miembros paralelos o casi paralelos.



Applicable welds

Square–Groove	Edge–Flange
Bevel–Groove	Corner–Flange
V–Groove	Seam
U–Groove	Edge
J–Groove	

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edge preparation. The surface prepared on the edge of a member for welding.
preparación de orilla. La superficie preparada en la orilla de un miembro que se va a soldar.

effective length of weld. The length of weld throughout which the correctly proportioned cross section exists. In a curved weld, it shall be measured along the axis of the weld.
distancia efectiva de soldadura. La distancia de una sección transversa correctamente proporcionada que existe por toda la soldadura. En una soldadura en curva, debe medirse por el axis de la soldadura.

effective throat. The minimum distance from the root of a weld to its face, less any reinforcement. See also joint penetration. Refer to drawing for convexity.
garganta efectiva. La distancia mínima de la raíz a la cara de una soldadura, menos el refuerzo. Vea también penetración de junta. Refiérase al dibujo para convexidad.

***elastic limit.** The maximum force that can be applied to a material or joint without causing permanent deformation or failure.
limite elástico. La fuerza máxima que se le puede aplicar a un material o junta sin causar deformación o falta permanente.

***elbow.** The joint that connects a robot's upper arm and forearm.
codo. La junta que conecta al brazo de arriba con el brazo de enfrente en un robot.

electrode (E). A component of the secondary circuit terminating at the arc, molten conductive slag, or base metal.
electrodo (E). Un componente del circuito eléctrico que termina al arco, escoria derretida conductiva, o metal base.

***electrode angle.** The angle between the electrode and the surface of the metal; also known as the direction of travel (leading angle or trailing angle); leading angle pushes molten metal and slag ahead of the weld; trailing angle pushes the molten metal away from the leading edge of the molten weld pool toward the back, where it solidifies.
ángulo del electrodo. El ángulo en medio del electrodo y la superficie del metal; también conocido como la dirección de avance (apuntado hacia adelante o apuntado hacia atras); el ángulo apuntado empuja el metal derretido y la escoria enfrente de la soldadura; y el ángulo apuntado hacia atrás empuja el metal derretido lejos de la orilla delantera del charco del metal derretido hacia atrás, donde se solidifica.

***electrode classification.** Any of several systems developed to identify shielded metal arc welding electrodes. The most widely used identification system was developed by the American Welding Society (AWS). The information represented by the classification generally includes the minimum tensile strength of a good weld, the position(s) in which the electrode can be used, the type of flux coating, and the type(s) of welding currents with which the electrode can be used.
clasificación de electrodo. Cualquiera de los varios sistemas desarollados para identificar electrodos protegidos para soldadura de arco. El sistema de identificación que se usa mucho más fue desarrollado por la Sociedad de Soldadura Americana (AWS). La información representada por la clasificación generalmente incluye la fuerza tensible mínima de una soldadura, la posición(es) donde se puede usar el electrodo, el tipo de recubrimiento de fundente y los tipo(s) de corrientes para soldar con la cual se puede usar el electrodo.

electrode extension (GMAW, FCAW, SAW). The length of unmelted electrode extending beyond the end of the contact tube during welding.
extensión del electrodo (GMAW, FCAW, SAW). La distancia de extensión del electrodo que no está derretido más allá de la punta del tubo de contacto durante la soldadura.

electrode holder. A device used for mechanically holding and conducting current to an electrode or electrode adapter.
porta electrodo. Un aparato usado para detener mecánicamente y conducir corriente a un electrodo durante la soldadura.

electrode lead. The secondary circuit conductor transmitting energy from the power supply to the electrode holder, gun, or torch. Refer to drawing for direct-current electrode negative.
cable de electrodo. Un conductor eléctrico en medio de la fuente para la corriente de soldar con arco y el portaelectrodo. Refiérase al dibujo de corriente directa con electrodo negativo.

electrode setback. The distance the electrode is recessed behind the constricting orifice of the plasma arc torch or thermal spraying gun, measured from the outer face of the nozzle.
retroceso del electrodo. La distancia del hueco del electrodo que está detrás del orificio constringente de la antorcha de arco plasma o pistola de rocio termal, se mide de la cara de afuera a la boquilla.

***electrode tip.** The end of an electrode where the arc jumps from the electrode to the work.
punta del electrodo. Extremo de un electrodo donde el arco salta desde el electrodo hasta la zona de la pieza de trabajo.

electron beam cutting (EBC). A thermal cutting process severing metals by melting them with the heat from a concentrated beam composed primarily of high-velocity electrons, impacting upon the workpieces.
cortes a rayo de electron (EBC). Un proceso de cortar que usa calor obtenido de un rayo concentrado primeramente de electrones de alta velocidad que choca sobre la pieza de trabajo la cual se va a cortar; puede o no usar un gas surtido externamente.

electron beam welding (EBW). A welding process that produces coalescence with a concentrated beam, composed primarily of high-velocity electrons, impinging on the joint. The process is used without shielding gas and without the application of pressure.
soldadura a rayo de electron (EBW). Un proceso de soldadura la cual produce coalescencia de un rayo concentrado, compuesto primeramente de electrones de alta velocidad al chocar con la junta. Este proceso no usa gas de protección y sin la aplicación de presión.

***electrons.** Small particle of an atom whose movement is associated with electrical flow.
electrones. Partículas pequeñas de un átomo cuyo movimiento está asociado con el flujo eléctrico.

electroslag welding electrode. A filler metal component of the welding circuit through which current is conducted from the electrode guiding member to the molten slag.
electrodo para soldadura de electroescoria. Un componente de metal de relleno del circuito para soldar por donde la corriente es conducida del miembro que guía el electrodo a la escoria derretida.

emissive electrode. A filler metal electrode consisting of a core of a bare electrode or a composite electrode to which a very light coating has been applied to produce a stable arc.
electrodo emisivo. Un electrodo de metal de relleno consistiendo de un electrodo liso o un electrodo compuesto de una capa ligera que se le aplica para producir un arco estable.

***end effector.** An actuator, a gripper, or a mechanical device attached to the wrist of a manipulator by which objects can be grasped or acted upon.
punta que efectúa. Un movedor, el que agarra, o un aparato mecánico fijo a la muñeca de un manipulador por el cual objectos se pueden agarrar u obrar en impulso.

entry-level welder. A person just entering the welding profession.
soldador principiante. Una persona que acaba de comenzar en la profesión de la soldadura.

***error signal.** The difference between desired response and actual response.
señal equivocada. La diferencia entre la respuesta deseada y la respuesta efectiva.

***etching.** The process of chemically preparing the surface of a specimen so that the metal's grain can be examined.
decapado. Proceso para preparar químicamente la superficie de un espécimen de modo que el grano del metal pueda ser examinado.

***eutectic composition.** The composition of an alloy that has the lowest possible melting point for that mixture of metals.
composición de tipo eutectico. La composición de un aleado que tenga el punto de fusión lo más bajo posible para esa mezcla de metales.

***evacuated (vacuum) chamber.** A device that is used to reduce or remove the atmosphere around a part(s) being welded to prevent weld contamination.
cámara de evacuación (vacío). Dispositivo que se usa para reducir o extraer el aire que rodea la(s) pieza(s) que se suelda(n) para prevenir la contaminación.

***exhaust pickup.** A component of a forced ventilation system that has sufficient suction to pick up fumes, ozone, and smoke from the welding area and carry the fumes, etc., outside of the area.
recogedor de extracción. Un componente de un sistema de ventilación forzada que tiene suficiente succión para recoger vaho, ozono, y humo de la área de soldadura y lleva al vaho, etc., a fuera de la area.

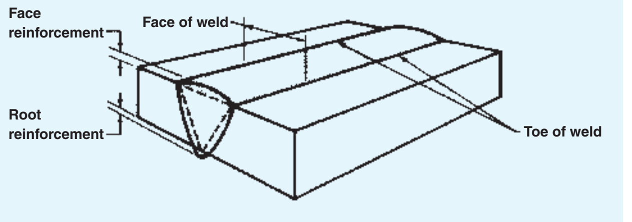
***exothermic gases.** Gases that react with the material being cut and produce additional heat.
gases exotérmicos. Gases que reaccionan con el material que se corta y producen calor adicional.

***extension line.** Lines in a drawing that extend from an object which locate the points being dimensioned.
***línea de extensión.** Líneas de un dibujo que se extienden desde un objeto y que ubican los puntos que se miden.

F

***fabrication.** An assembly whose parts may be joined by a combination of methods, including welds, bolts, screws, adhesives, etc.
conjunto. Un conjunto cuyas partes pueden estar unidas por una combinación de métodos que incluyen soldaduras, pernos, tornillos, adhesivos, etc.

face of weld. The exposed surface of a weld on the side from which welding was done.
cara de la soldadura. La superficie expuesta de una soldadura del lado de donde se hizo la soldadura.



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face reinforcement. Reinforcement of a weld at the side of the joint from which welding was done. See also root reinforcement. Refer to drawing for face of weld.
refuerzo de cara. Refuerzo de una soldadura en el lado de la junta de donde se hizo la soldadura. Vea también refuerzo de raíz. Refiérase al dibujo para cara de la soldadura.

face shield. A device positioned in front of the eyes and a portion of, or all of, the face, whose predominant function is protection of the eyes and face. See also helmet.

protector de cara sostenido a mano. Un aparato puesto en frente de los ojos y una porción, o en toda la cara, cuya función predominante es de proteger los ojos y la cara. Vea también casco.

face-bend test. A test in which the weld face is on the convex surface of a specified bend radius.
prueba de dobléz de cara. Una prueba donde la cara de la soldadura está en la superficie convexa al radio de dobléz especificado.

face-centered cubic (FCC). Crystal form of iron above 1675°F (913°C) and called austenite.
red cúbica centrada en las caras (FCC). Forma cristalina del hierro a más de 1675°F (913°C) denominada austenita.

***fast-freezing electrode.** An electrode whose flux forms a high-temperature slag that solidifies before the weld metal solidifies, thus holding the molten metal in place. This is an advantage for vertical, horizontal, and overhead welding positions.
electrodo de congelación rápida. Un electrodo cuyo flujo forma una escoria a temperaturas altas que se puede solidificar antes de que el metal de soldadura se pueda solidificar, asi detiene el metal derretido en su lugar. Está es una ventaja en soldaduras de posiciones vertical, horizontal y sobrecabeza.

***fatigue failures.** The failure of a part that is subjected to repeated forces below the normal static breaking point.
fallas por fatiga. Falla de una pieza que está sujeta a fuerzas repetitivas por debajo del punto de ruptura estático normal.

***fatigue resistance.** As applied to a soldered or brazed joint, it is the ability of the joint to be bent repeatedly without exceeding its elastic limit and without failure. Generally, fatigue resistance is low for most soldered and brazed joints.
resistencia a la fatiga. Como aplicada a una junta de soldadura con metales de bajo punto de fusión y soldadura fuerte, es la abilidad de una junta de ser doblada repetidamente sin exceder los limites elásticos y sin fracaso. Generalmente, la resistencia a la fatiga es muy baja para la mayoría de las juntas de soldadura con bajo punto de fusión y soldadura fuerte.

faying surface. The mating surface of a workpiece in contact with or in close proximity to another workpiece to which it is to be joined.
superficie de unión. La superficie de apareamiento de un miembro del que está en contacto con otro miembro o está en proximidad cercana a otro miembro que está para ser unido.

feed rollers. A set of two or four individual rollers that, when pressed tightly against the filler wire and powered up, feed the wire through the conduit liner to the gun for GMAW and FCAW welding.
rodillos de alimentación. Un conjunto de dos o cuatro rodillos individuales que al ser presionados fuertemente contra el alambre de relleno y ser accionados alimentan al alambre a través del revestimiento de canal hasta la pistola, en soldaduras tipo GMAW y FCAW.

***ferrite.** A body-centered cubic crystalline structure that iron forms as it changes from a liquid to a solid. See also crystalline structures.
ferrita. Estructura cristalina de red cúbica centrada en el cuerpo que el hierro forma a medida que cambia de líquido a sólido. Ver también estructura espacial cristalina.

***ferrous filler metals.** Filler metals comprised primarily of iron (steel).
metal de aporte ferroso. Metal de aporte compuesto principalmente de hierro (acero).

filler metals. The metals or alloys to be added in making a brazed, soldered, or welded joint.
metales de aporte. Los metales o aleados que se agregan cuando se hace una soldadura blanda o soldadura fuerte.

***filler pass.** One or more weld beads used to fill the groove with weld metal. The bead must be cleaned after each pass to prevent slag inclusions.
pasada para rellenar. Uno o más cordones de soldadura usados para llenar la ranura con el metal de soldadura. El cordón debe ser limpiado después de cada pasada para prevenir inclusiones de escoria.

fillet weld. A weld of approximately triangular cross section joining two surfaces approximately at right angles to each other in a lap joint, tee joint, or corner joint. Refer to drawing for convexity.
soldadura de filete. Una soldadura de filete de sección transversa aproximadamente triangular que une dos superficies aproximademente en ángulos rectos de uno al otro en junta de traslape, junta en-T-o junta de esquina. Refiérase al dibujo para convexidad.

fillet weld break test. A test in which the specimen is loaded so that the weld root is in tension.
prueba de rotura en soldadura de filete. Una prueba en donde la probeta es cargada de manera en que la tensión esté sobre la soldadura.

fillet weld leg. The distance from the joint root to the toe of the fillet weld.
pierna de soldadura filete. La distancia de la raíz de la junta al pie de la soldadura filete.

fillet weld size. For equal leg fillet welds, the leg lengths of the largest isosceles right triangle that can be inscribed within the fillet weld cross section. For unequal leg fillet welds, the leg lengths of the largest right triangle that can be inscribed within the fillet weld cross section.
tamaño de soldadura filete. Para soldaduras de filete que tienen piernas iguales, lo largo de las piernas del isósceles más grande del triángulo recto que puede ser inscribido dentro de la sección. Para soldaduras de filete con piernas desiguales, lo largo de las piernas del triángulo recto más grande puede inscribirse dentro de la sección transversal.

filter plate. An optical material that protects the eyes against excessive ultraviolet, infrared, and visible radiation.
lente filtrante. Un material óptico que protege los ojos contra ultravioleta excesiva, infrarrojo, y radiación visible.

final current. The current after downslope but prior to current shutoff.
corriente final. La corriente después del pendiente en descenso pero antes de que la corriente sea cerrada.

fisheye. A discontinuity, attributed to the presence of hydrogen in the weld, observed on the fracture surface of a weld in steel that consists of a small pore or inclusion surrounded by an approximately round, bright area.
ojo de pescado. Una discontinuidad que se encuentra en una fractura de superficie en una soldadura de acero que consiste de poros pequeños o inclusiones rodeadas de áreas aproximadamente redondas y brillantes.

***fissure.** A small, crack-like discontinuity with only slight separation (opening displacement) of the fracture surfaces. The prefixes *macro* and *micro* indicate relative size.
hendemiento. Una pequeña, discontinuidad como una grieta con solamente una separación (abertura desalojada) de las superficies fracturadas. El prefijo marco y micro indica el tamaño relativo.

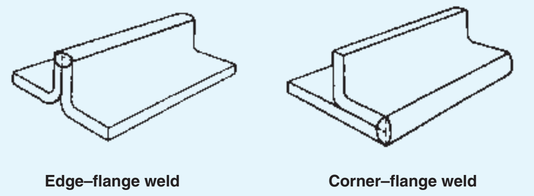
***fixed inclined (6G) position.** For pipe welding, the pipe is fixed at a 45° angle to the work surface. The effective welding angle changes as the weld progresses around the pipe.
posición (6G) inclinado fijo. Para soldadura de tubo, el tubo se fija a un ángulo de 45° de la superficie del trabajo. El ángulo efectivo de la soldadura cambia cuando la soldadura progresa alrededor del tubo.

fixture. A device designed to maintain the fit of a workpiece(s) in proper relationship.
fijación. Una devisa diseñada para detener partes que se van a unir en relación propia de una a la otra.

***flame propagation rate.** The speed at which flame travels through a mixture of gases.
cantidad de propagación de la llama. La rapidez en que la llama camina a través de una mezcla de gas.

flame spraying (FLSP). A thermal spraying process in which an oxyfuel gas flame is the source of heat for melting the surfacing material. Compressed gas may or may not be used for atomizing the propellant and surfacing material to the substrate.
rociado a llama (FLSP). Un proceso de rociado termal en donde la llama del gas oxicombustible es la fuente de calor para derretir el material de revestimiento. El gas comprimido se puede o no se puede usar para automizar el propulsor y el material de revestimiento al substrato.

flange weld. A weld made on the edges of two or more joint members, at least one of which is flanged.
soldadura de reborde. Una soldadura que se hace en las orillas de dos o más miembros de junta, donde por lo menos uno tiene reborde.



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flash. The material that is expelled or squeezed out of a weld joint and that forms around the weld.
ráfaga. El material que es despedido o exprimido fuera de una junta de soldadura y se forma alrededor de la soldadura.

***flash burn.** An arc-caused burn typically on the eye that results from an extremely brief exposure to the direct ultraviolet light produced by an arc welding process.
quemadura de relámpago. Quemadura causada por arco, por lo general en el ojo, y que resulta de la exposición extremadamente breve a la luz ultravioleta directa producida por un proceso de soldadora con arco.

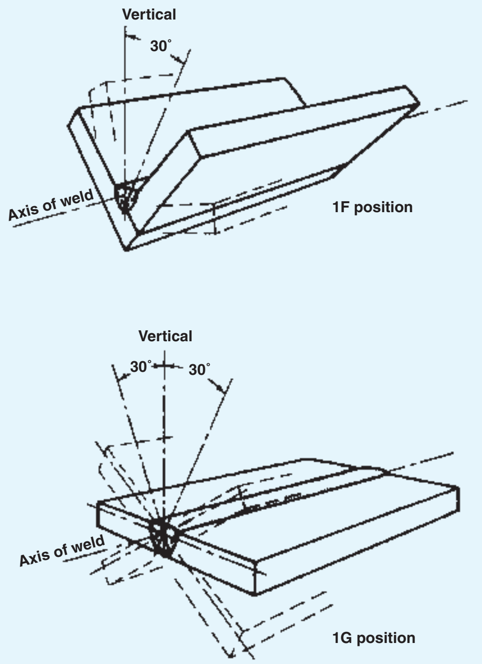
***flash glasses.** Lightly tinted safety glasses, usually a number two shade, worn by welders to protect themselves from flash burns as well as flying debris.
anteojos de relámpago. Anteojos de seguridad sombreados, por lo general con sombra n°2, que los soldadores usan para protegerse de las quemaduras de relámpago y fragmentos de soldadura.

flash welding (FW). A resistance welding process producing a weld at the faying surfaces of a butting member by the rapid upsetting of the workpiece after a controlled period of flashing action.
soldadura de relámpago (FW). Un proceso de soldadura de resistencia que produce una soldadura en el empalme de la superficie de una junta tope por una acción de relampagueo y por la aplicación de presión después que el calentamiento este substancialmente acabado. La acción del relampagueo, causado por densidades de corrientes altas a unos puntos de contacto pequeños en medio de las piezas de trabajo, despiden fuertemente el material de la junta cuando las piezas de trabajo se mueven despacio. La soldadura es terminada por un acortamiento rápido de las piezas de trabajo.

flashback. A recession of the flame through the torch and hose, regulator, and/or cylinder, potentially causing an explosion.
llamarada de retroceso. Una recesión de la llama adentro o atrás de la cámara mezcladora de una antorcha de gas oxicombustible o pistola de rociar a llama.

flashback arrester. A device to limit damage from a flashback by preventing propagation of the flame front beyond the point at which the arrester is installed.
válvula de retención. Un aparato para limitar el daño de una llamarada de retroceso para prevenir la propagación del frente de la llama más allá del punto donde se instala la válvula de retención.

flat position. The position used to weld from the upper side of the joint resulting in the face of the weld being oriented approximately horizontal.
posición plana. La posición de soldadura que se usa para soldar del lado de arriba de una junta; la cara de la soldadura está aproximadamente horizontal.



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flaw. An undesirable discontinuity.
falta. Una discontinuidad indeseable.

flow rate. The rate at which a given volume of shielding gas is delivered to the weld zone. The units used for welding are cubic feet, inches, meters, and centimeters.
caudal. Velocidad a la cual llega un determinado volumen de gas protector a la zona de soldadura. Las unidades usadas para la soldadura son pies cúbicos, pulgadas, metros, y centímetros.

flux. A material applied to the workpiece(s) before or during joining or surfacing to cause interactions that remove oxides and other contaminants, improve wetting, and affect the final surface profile. Welding flux may also affect the weld metal chemical composition.
flujo. Un material que se usa para impedir o prevenir la formación de óxidos y otras substancias indeseables en el metal derretido y en las superficies del metal sólido, y para desolver o de otra manera facilitar el removimiento de dichas substancias.

flux cored arc welding (FCAW). An arc welding process using an arc between a continuous filler metal electrode and the weld pool. The process is used with shielding gas from a flux contained within the tubular electrode, with or without additional shielding from an externally supplied gas, and without the application of pressure.
soldadura de arco con núcleo de fundente (FCAW). Un proceso de soldadura de arco que usa un arco entre medio de un electrodo de metal rellenado continuo y el charco de la soldadura. El proceso es usado con gas de protección del flujo contenido dentro del electrodo tubular, y sin usarse protección adicional de abastecimiento de gas externo, y sin aplicarse presión.

flux cored electrode. A composite tubular filler metal electrode consisting of a metal sheath and a core of various powdered materials, producing an extensive slag cover on the face of a weld bead.
electrodo de núcleo de fundente. Un electrodo tubular de metal para rellenar con una compostura que consiste de una envoltura de metal y un núcleo con varios materiales de polvo, que producen un forro extensivo de escoria en la superficie del cordón de soldadura. Protección externa puede ser requerida.

flux cover. In metal bath dip brazing and dip soldering, a cover of flux over the molten filler metal bath.
tapa de fundente. En metal de baño soldadura fuerte y soldadura blanda por inmersión, una tapa de fundente sobre el baño del metal de relleno derretido.

***forced ventilation.** To remove excessive fumes, ozone, or smoke from a welding area, a ventilation system may be required to supplement natural ventilation. Where forced ventilation of the welding area is required, the rate of 200 cu ft (56 m^3) or more per welder is needed.
ventilación forzada. Para quitar excesivo vaho, ozono y humo de la área donde se solda, un sistema de ventilación puede ser requerido para suplementar la ventilación natural. Donde la ventilación forzada de la área de la soldadura es requerida, la rázon de 200 pies cúbicos (56 m^3) o más es requerido por cada soldador.

forehand welding. A welding technique in which the welding torch or gun is directed toward the progress of welding. See also travel angle, work angle, and push angle. Refer to drawing for backhand welding.
soldadura directa. Una técnica de soldar en cual la pistola o la antorcha para soldar es dirigida hacia al progreso de la soldadura. Vea también ángulo de avance, ángulo de trabajo, y ángulo de empuje. Refiérase al dibujo soldadura en revés.

forge welding (FOW). A solid state welding process producing a weld by heating the workpieces to the welding temperature and applying sufficient blows to cause permanent deformation at the faying surfaces.
soldadura por forjado. Un proceso de soldadura de estado sólido que produce una soldadura calentando las piezas de trabajo a una temperatura de soldadura y aplicando golpes suficientes para causar una deformación permanente en las superficies del empalme.

***frequency.** As it relates to alternating current, this refers to the rate that the current reverses direction.
frecuencia. En relación a corriente alterna. Velocidad a la que la corriente revierte su polaridad.

***frogs.** The large rail structures, usually castings, that form the center of a crossing or the rail crossing point of a switch.
corazónes de cruzamiento. Las grandes estructuras de rieles, normalmente piezas moldeadas, que forman el centro de un cruzamiento o el punto de cruzamiento de rieles en el sitio de convergencia.

fuel gases. A gas, when mixed with air or oxygen and ignited, producing heat for cutting, joining, or thermal spraying.
gases combustibles. Gases como acetileno, gas natural, hidrógeno, propano, metilacetileno propodieno estabilizado, y otros combustibles normalmente usados con oxígeno en uno de los procesos de oxicombustible y para calentar.

***full face shield.** Personal protective device to protect the eyes and face from flying debris; it may be clear or tinted.
protector facial completo. Dispositivo de protección personal que protege los ojos y el rostro de fragmentos volantes; puede ser transparente o sombreado.

full fillet weld. A fillet weld whose size is equal to the thickness of the thinner member joined.
soldadura de filete llena. Una soldadura de filete cuyo tamaño es igual de grueso como el miembro más delgado de la junta.

full penetration. A nonstandard term for complete joint penetration.
penetración llena. Un término fuera de la norma en vez de la penetración de junta.

furnace brazing (FB). A brazing process in which assemblies are heated to the brazing temperature in a furnace.
soldadura fuerte en horno (FB). Un proceso de soldadura fuerte en donde las partes que se van a unir se ponen en un horno calentado a una temperatura adecuada.

furnace soldering (FS). A soldering process using heat from a furnace or oven.
soldadura blanda en horno (FS). Un proceso de soldadura blanda en donde las partes que se van a unir se ponen en un horno calentado a una temperatura adecuada.

fusion. The melting together of filler metal and base metal, or of base metal only, to produce a weld. See also depth of fusion.
fusión. El derretir el metal de relleno y el metal base juntos o el metal base solamente, para producir una soldadura. Vea también grueso de fusión.

fusion welding. Any welding process or method that uses fusion to complete the weld.
soldadura de fusión. Cualquier proceso de soldadura o método que usa fusión para completar la soldadura.

fusion zone. The area of base metal melted as determined on the cross section of a weld. Refer to drawing for depth of fusion.
zona de fusión. La área del metal base que se derritió como determinada en la sección transversa de la soldadura. Refiérase al dibujo grueso de fusion.

G

gap. A nonstandard term when used for arc length, joint clearance, and root opening.
abertura. Un término fuera de norma cuando se usa en lugar del arco, despejo de junta, y abertura de raíz.

gas cup. A nonstandard term for gas nozzle.
tazón de gas. Un término fuera de norma en vez de boquilla de gas.

gas cylinder. A portable container used for transportation and storage of compressed gas.
cilindro de gas. Un recipiente portátil que se usa para transportación y deposito de gas comprimido.

***gas laser.** A laser in which the lasing medium is a gas.
láser de gas. Tipo de láser cuyo medio de transmisión es un gas.

gas lens. One or more fine mesh screens located in the torch nozzle to produce a stable stream of shielding gas. Primarily used for gas tungsten arc welding.
lente para gas. Uno o más cedazos de malla fina localizados en la lanza de la antorcha para producir un chorro estable de gas de protección primeramente usada para soldaduras de arco tungsteno y gas.

gas metal arc cutting (GMAC). An arc cutting process employing a continuous consumable electrode and a shielding gas.
cortes de arco metálico con gas (GMAC). Un proceso de corte con arco que usa un alambre consumible continuo y un gas de protección.

gas metal arc welding (GMAW). An arc welding process using an arc between a continuous filler metal electrode and the weld pool. The process is used with shielding from an externally supplied gas and without the application of pressure.
soldadura de arco metálico con gas (GMAW). Un proceso de soldar con arco que usa un arco en medio de un electrodo de metal para rellenar continuo y el charco de soldadura. El proceso usa protección de un abastecedor externo de gas y sin la aplicación de presión.

gas metal arc welding-pulsed arc (GMAW-P). A gas metal arc welding process variation in which the current is pulsed.
soldadura con arco metálico con gas arco pulsado (GMAW-P). Un proceso de soldadura de arco metálico con gas con variación en cual la corriente es de pulsación.

gas metal arc welding-short-circuit arc (GMAW-S). A gas metal arc welding process variation in which the consumable electrode is deposited during repeated short circuits. Sometimes this process is referred to as MIG or CO_2 welding (nonpreferred terms).
soldadura con arco metálico con gas-arco de corto circuito (GMAW-S). Un proceso de soldadura de arco metálico con gas variación en cual el electrodo consumible es depositado durante los cortos circuitos repetidos. A veces el proceso es referido como soldadura MIG o CO_2 (términos que no son preferidos).

gas nozzle. A device at the exit end of the torch or gun that directs shielding gas.
boquilla de gas. Un aparato a la salida de la punta de la antorcha o pistola que dirige el gas protector.

gas regulator. A device for controlling the delivery of gas at some substantially constant pressure.
regulador de gas. Un aparato para controlar la salida de gas a una presión substancialmente constante.

gas tungsten arc cutting (GTAC). An arc cutting process employing a single tungsten electrode with gas shielding.
corte de arco con tungsteno y gas (GTAC). Un proceso de corte de arco que usa un electrodo de tungsteno sencillo con gas de protección.

gas tungsten arc welding (GTAW). An arc welding process using an arc between a tungsten electrode (nonconsumable) and the weld pool. The process is used with shielding gas and without the application of pressure.
soldadura de arco de tungsteno con gas (GTAW). Un proceso de soldadura de arco que usa un arco en medio del electrodo tungsteno (no consumible) y el charco de la soldadura. El proceso es usado con gas de protección y sin aplicación de presión.

gas tungsten arc welding-pulsed arc (GTAW-P). A gas tungsten arc welding process variation in which the current is pulsed.
soldadura de arco de tungsteno con gas-arco pulsado (GTAW-P). Un proceso de soldadura de arco tungsteno con variación en cual la corriente es de pulsación.

***gauge** (regulator). A device mounted on a regulator to indicate the pressure of the gas passing into the gauge. A regulator is provided with two gauges—one (high-pressure gauge) indicates the pressure of the gas in the cylinder; the second gauge (low-pressure gauge) shows the pressure of the gas at the torch.
manómetro (regulador). Un aparato montado en un regulador para indicar la presión del gas que está pasando por el manómetro. El regulador tiene dos manómetros—uno (manómetro de alta presión) indica la presión del gas en el cilindro; el segundo manómetro (manómetro de presión baja) enseña la presión del gas en la antorcha.

***gauge pressure.** The actual pressure shown on the gauge; does not take into account atmospheric pressure.
manómetro para presión. La presión actual que se enseña en el manómetro; no toma en cuenta la presión atmosférica.

***GFCI.** Ground fault circuit interrupters are fast-acting circuit breakers that shut off the power to an electrical circuit when they detect a small imbalance in the circuit's electrical flow.
ICFCT. Interruptor del circuito de fallos de conexión a tierra. Tipo de interruptor de circuito de acción rápida que corta el suministro eléctrico a un circuito cuando detecta un pequeño desequilibrio en el flujo eléctrico del circuito.

***globular transfer.** The transfer of molten metal in large drops from a consumable electrode across the arc.
traslado globular. El traslado del metal derretido en gotas grandes de un electrodo consumible a través del arco.

***goggles.** Personal protective device to protect the eyes from flying debris; may be clear or tinted.
gafas. Equipo de protección personal para proteger los ojos de fragmentos volantes; pueden ser transparentes o sombreadas.

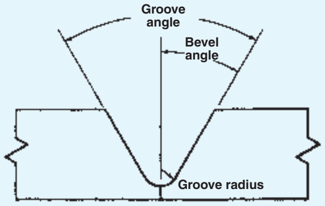
gouging. The forming of a bevel or groove by material removal. See also back gouging, arc gouging, and oxygen gouging.
escopleando con gubia. Formando un bisel o ranura removiendo el material. Vea también gubia trasera, gubia dura con arco, y escopleando con la gubia con oxígeno.

***grain refinement.** Is the process that occurs when larger metallic grain structures break down in size. Grain refinement can be associated with a change in temperature, mechanical working, or time.
refinamiento por grano. Proceso que ocurre cuando estructuras metálicas de granos mayores se rompen. El refinamiento por grano puede estar asociado con un cambio en temperatura, procesos mecánicos, o tiempo.

***graphite.** A form of carbon.
grafito. Una de las formas del carbón.

groove. An opening or a channel in the surface of a part or between two components, that provides space to contain a weld.
ranura. Una abertura o un canal en la superficie de una parte o en medio de dos componentes, la cual provee espacio para contener una soldadura.

groove angle. The total included angle of the groove between parts to be joined by a groove weld.
ángulo de ranura. El ángulo total incluido de la ranura entre partes para unirse por una soldadura de ranura.



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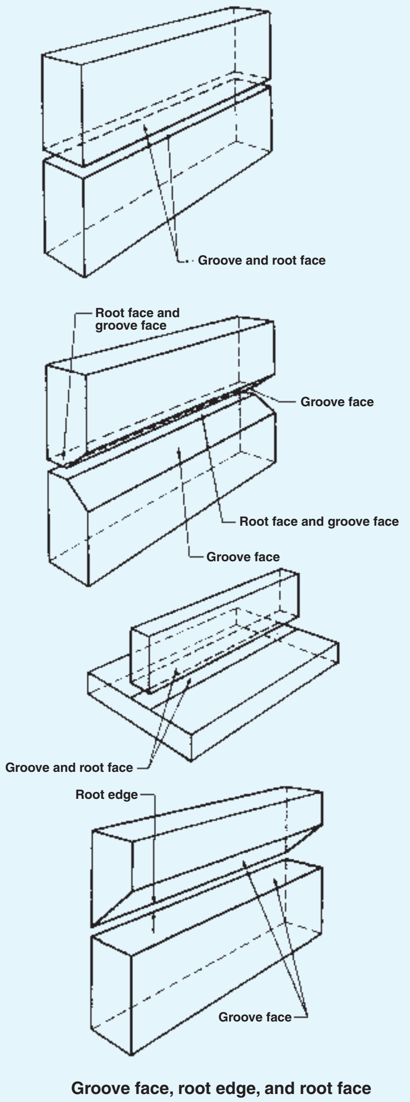
groove face. The surface of a joint member included in the groove.
cara de ranura. La superficie de un miembro de una junta incluido en la ranura.



Groove face, root edge, and root face

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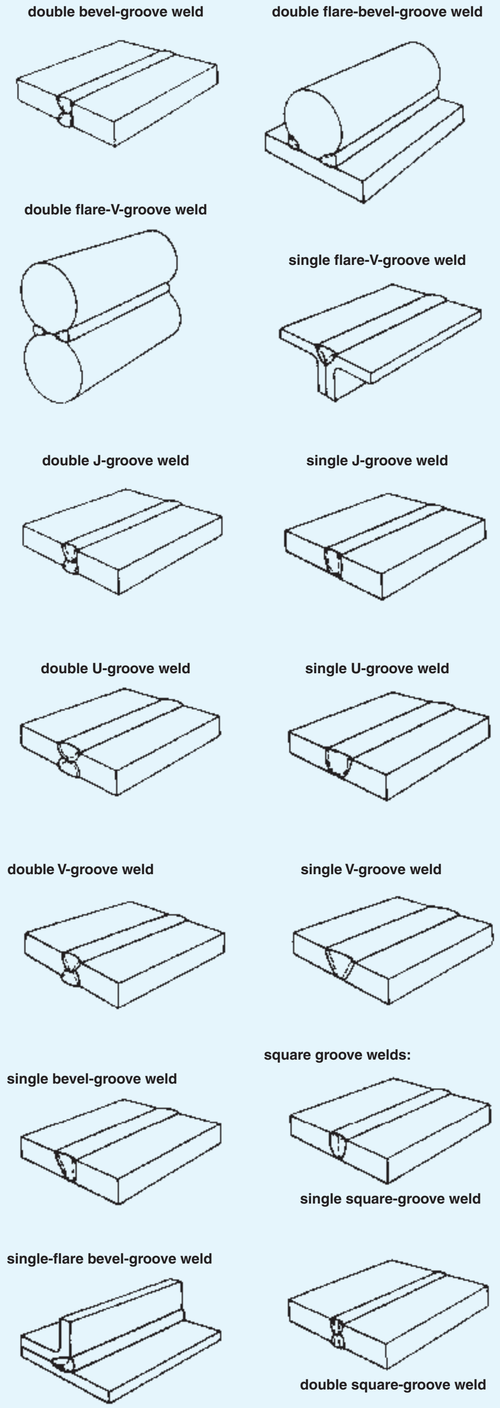
groove radius. The radius used to form the shape of a J- or U-groove weld joint. Refer to drawings for bevel.
radio de ranura. La radio que se usa para formar una junta de una soldadura con una ranura de forma U o J. Refiérase a los dibujos para bisel.

groove weld. A weld made in the groove between two members to be joined. The standard types of groove welds are shown in the drawings.
soldadura de ranura. Una soldadura hecha en la ranura dentro de dos miembros que se unen. Los tipos normales de soldadura de ranura se ven en los dibujos.



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ground connection. An electrical connection of the welding machine frame to the earth for safety.
conexión a tierra. Una conexión eléctrica del marco de la máquina de soldar a la tierra para seguridad.

ground lead. A nonstandard and incorrect term for workpiece lead.
cable de tierra. Un término fuera de norma e incorrecto que se usa en vez de cable de pieza de trabajo.

***group technology.** A system for coding parts based on similarities in geometrical shape or other characteristics of parts. The grouping of parts into families based on similarities in their production so that parts of a particular family could be processed together.
codificador. Un sistema para codificar partes basadas en similaridades en forma geométrica y otras características de las partes. La agrupación de partes en familias basadas en similaridades en su producción para que partes de una familia en particular puedan ser procesadas juntas.

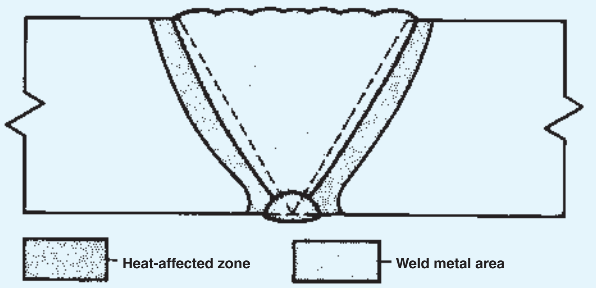
***guided-bend specimen.** Any bend specimen that will be bend-tested in a fixture that controls the bend radii, such as the AWS bend-test fixture.
probeta de dobléz guiada. Cualquier probeta de dobléz en la cual se va a hacer un dobléz guiado en una máquina que controla el radio del dobléz, como la máquina de dobléz guiado del AWS.

H

hardfacing. A surfacing variation in which surfacing material is deposited to reduce wear.
endurecimiento de caras. Una variación superficial donde el material superficial es depositado para reducir el desgastamiento.

heat-affected zone (HAZ). The portion of the base metal whose mechanical properties or microstructure has been altered by the heat of welding, brazing, soldering, or thermal cutting.
zona afectada por el calor (HAZ). La porción del metal base cuya propiedad mecánica o microestructura ha sido alterada por el calor de soldadura, soldadura fuerte, soldadura blanda, o corte termal.

***heat treatments.** Postweld heat treatment to reduce weld stresses is the most common type of heat treatment used on weldments.
tratamiento con calor. Tratamiento térmico posterior a la soldadura para reducir la tensión de la soldadura. Es el tipo más común de tratamiento térmico que se utiliza en soldaduras.



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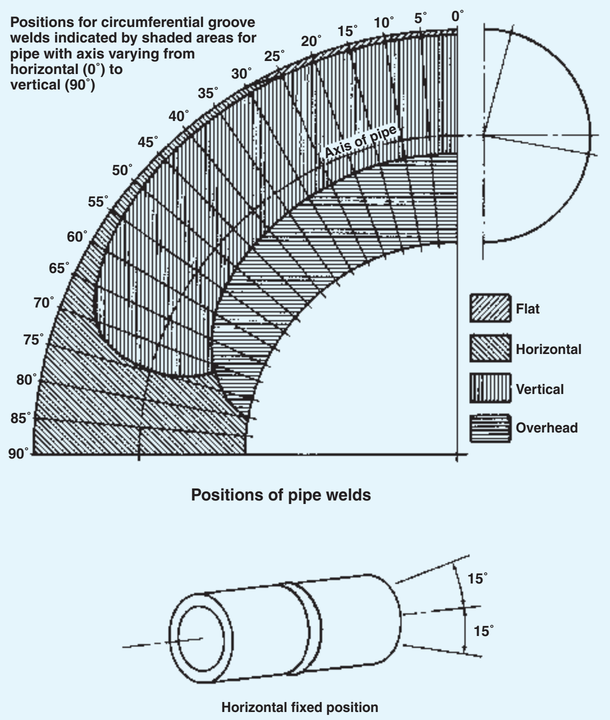
heating torch. A device for directing the heating flame produced by the controlled combustion of fuel gases.
antorcha de calentamiento. Un aparato para dirigir la llama de calentamiento que es producida por una combustión controlada de gases de combustión.

helmet. A device designed to be worn on the head to protect eyes, face, and neck from arc radiation, radiated heat, spatter, or other harmful matter expelled during arc welding, arc cutting, and thermal spraying.
casco. Un aparato diseñado para usarse sobre la cabeza para proteger ojos, cara y cuello de radiación del arco, calor radiado, salpicadura, u otra materia dañosa despedida durante la soldadura de arco, corte por arco, y rociado termal.

***hidden line.** Lines on a drawing that show the same features as object lines except that the corners, edges, and curved surfaces cannot be seen because they are hidden behind the surface of the object.
línea oculta. Líneas de un dibujo que muestran las mismas características como líneas de objetos, excepto que las esquinas, los bordes y las superficies curvas no se pueden visualizar porque están ocultas detrás de la superficie del objeto.

***high-frequency alternating current.** Electric current that changes polarity at a rate higher than 3 million cycles a second (3 MHz).
corriente alterna de alta frecuencia. Corriente eléctrica que cambia la polaridad a una velocidad de 3 millones de ciclos por segundo (3 MHz).

horizontal fixed position (pipe welding). The position of a pipe joint in which the axis of the pipe is approximately horizontal and the pipe is not rotated during welding.
posición fija horizontal (soldadura de tubos). La posición de una junta de tubo la cual el axis del tubo es aproximadamente horizontal, y el tubo no da vueltas durante la soldadura.



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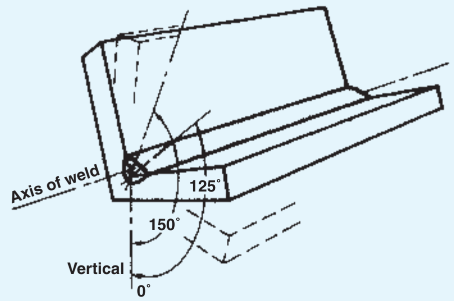
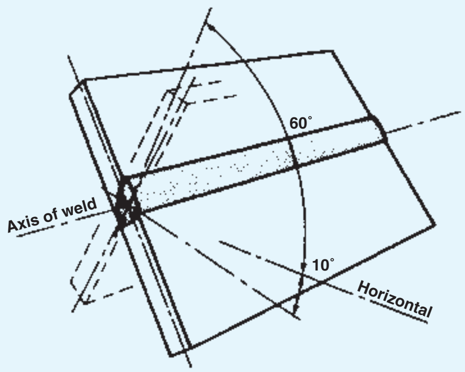
***horizontal fixed (5G) position weld.** For pipe welding, the pipe is fixed horizontally (cannot be rolled). The weld progresses from overhead, to vertical, to flat position around the pipe.
soldadura de posición fija horizontal (5G). Para soldadura de tubos, el tubo está fijo horizontalmente (no se pueder rodar). La soldadura progresa de sobre cabeza, a vertical, a la posición plana alrededor del tubo.

horizontal position (fillet weld). The position in which welding is performed on the upper side of an approximately horizontal surface and against an approximately vertical surface.
posición horizontal (soldadura de filete). La posición de la soldadura la cual es hecha en el lado de arriba de una superficie horizontal aproximadamente y junto a una superficie vertical aproximadamente.



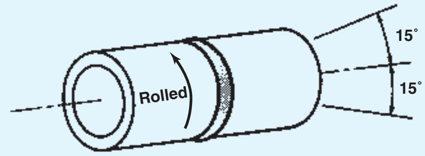
2F position
American Welding Society

horizontal position (groove weld). The position of welding in which the weld axis lies in an approximately horizontal plane and the weld face lies in an approximately vertical plane.
posición horizontal (de ranura). La posición para soldar en la cual el axis de la soldadura está en una plana horizontal aproximadamente, y la cara de la soldadura está en una plana vertical aproximadamente.



2G position
American Welding Society

horizontal rolled position (pipe welding). The position of a pipe joint in which the axis of the pipe is approximately horizontal and welding is performed in the flat position by rotating the pipe.
posición horizontal rodada (soldadura de tubo). La posición de una junta de tubo en la cual el axis del tubo es horizontal aproximadamente, y la soldadura se hace en la posición plana con rotación del tubo.



1G position
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***horizontal rolled (1G) position.** For pipe welding, this position yields high-quality and high-quantity welds. Pipe to be welded is placed horizontally on the welding table in a fixture to hold it steady and permit each rolling. The weld proceeds in steps, with the pipe being rolled between each step, until the weld is complete. For plate, see axis of a weld.
posición (1G) horizontal rodada. Para soldadura de tubo, está posición produce soldaduras de alta calidad y alta cantidad. El tubo que se va a soldar se pone horizontalmente sobre la mesa de soldadura en una instalación fija que lo detiene seguro y permite cada rodadura. La soldadura procede en pasos, con el tubo siendo rodado entre cada paso, hasta que la soldadura esté completa. Para plato, vea eje de la soldadura.

hot crack. A crack occurring in a metal during solidification or at elevated temperatures. Hot cracks can occur in both heat-affected (HAZ) and weld metal (WMZ) zones.
grieta caliente. Una grieta formada a temperaturas cerca de la terminación de la solidificación.

***hot pass.** The welding electrode is passed over the root pass at a higher-than-normal amperage setting and travel rate to reshape an irregular bead and turn out trapped slag. A small amount of metal is deposited during the hot pass so the weld bead is convex, promoting easier cleaning.
pasada caliente. El electrodo de soldadura se pasa sobre la pasada de raíz poniendo el amperaje más alto que lo normal y proporción de avance para reformar un cordón irregular y sacar la escoria atrapada. Una cantidad pequeña de metal es depositada durante la pasada caliente para que el cordón soldado sea convexo, promoviendo más fácil la limpieza.

hot start current. A very brief current pulse at arc initiation to stabilize the arc quickly. Refer to drawing for upslope time.
corriente caliente para empezar. Un pulso muy breve de corriente a iniciación de arco para estabilizar el arco aprisa. Refiérase al dibujo tiempo del pendiente en ascenso.

hydrogen embrittlement. The delayed cracking in steel that may occur hours, days, or weeks following welding. It is a result of hydrogen atoms that dissolved in the molten weld pool during welding.
fragilidad causada por el hidrógeno. El fisuramiento retardado en el acero que puede ocurrir horas, días o semanas después de la soldadura. Es el resultado de la disolución de átomos de hidrógeno en el charco de soldadura derretido durante la soldadura.

I

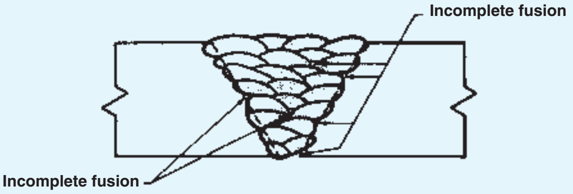
inclined position. The position of a pipe joint in which the axis of the pipe is at an angle of approximately 45° to the horizontal, and the pipe is not rotated during welding.
posición inclinada. Una posición de junta de tubo en la cual el axis del tubo está a un ángulo de aproximadamente 45° a la horizontal, y no se le da vueltas al tubo durante la soldadura.

inclined position, with restriction ring. The position of a pipe joint in which the axis of the pipe is at an angle of approximately 45° to the horizontal, and a restriction ring is located near the joint. The pipe is not rotated during welding.
posición inclinada con argolla de restricción. La posición de una junta de tubo en la cual el axis del tubo está a un ángulo de aproximadamente 45° a la horizontal, y una argolla de restricción está localizada cerca de la junta. No se le da vuelta al tubo durante la soldadura.

included angle. A nonstandard term for groove angle.
ángulo incluido. Un término fuera de norma para ángulo de ranura.

inclusion. Entrapped foreign solid material, such as slag, flux, tungsten, or oxide.
inclusión. Material extraño atrapado sólido, como escoria, flujo, tungsteno, u óxido.

incomplete fusion. A weld discontinuity in which fusion did not occur between weld metal and fusion faces or adjoining weld beads.
fusión incompleta. Una discontinuidad en la soldadura en la cual no ocurrió fusión entre el metal soldado y caras de fusión o cordones soldados inmediatos.



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incomplete joint penetration. Joint penetration that is unintentionally less than the thickness of the weld joint.
penetración de junta incompleta. Penetración de la junta que no es intencionalmente menos de lo grueso de la junta de soldar.

***induction.** The transfer of heat obtained from the resistance of the work pieces to the flow of induced high-frequency welding current.
inducción. Transferencia del calor obtenido de la resistencia de las piezas de trabajo al flujo de corriente inducida de soldadura de alta frecuencia.

induction brazing (IB). A brazing process using heat from the resistance of the assembly to induced electric current.
soldadura fuerte por inducción (IB). Un proceso de soldadura blanda que usa calor de la resistencia de las piezas de trabajo para inducir la corriente eléctrica.

induction soldering (IS). A soldering process in which the heat required is obtained from the resistance of the workpieces to induced electric current.
soldadura blanda por inducción (IS). Un proceso de soldadura blanda en el cual el calor requerido es obtenido de la resistencia de las piezas de trabajo a la corriente eléctrica inducida.

inert gas. A gas that does not react chemically with materials.
gas inerte. Un gas que normalmente no se combina químicamente con materiales.

***inertia welding.** A welding process in which one workpiece revolves rapidly and one is stationary. At a predetermined speed the power is cut, the rotating part is thrust against the stationary part, and frictional heating occurs. The weld bond is formed when rotation stops.
soldadura inercial. Un proceso en el cual una pieza de trabajo voltea rápidamente y la otra está fija. A una velocidad predeterminada se le corta la potencia, la parte que está volteando es empujada en contra de la parte fija, y el calor de fricción ocurre. La unión soldada es formada cuando se para la rotación.

***infrared light.** Light that has a wavelength longer than visible light with a wavelength ranging approximately from 1 THz to 430 THz.
luz infrarroja. Luz que tiene una longitud de onda mayor que la luz visible. Las longitudes de onda varían entre 1 THz a 430 THz.

infrared radiation. Electromagnetic energy with wavelengths from 770 to 12,000 nanómeters.
radiación infrarrojo. Energia electromagnética con longitud de ondas de 770 a 12,000 nanómetros.

***injector chamber.** One method of completely mixing the fuel gas and oxygen to form a flame. High-pressure oxygen is passed through a narrowed opening (venturi) to the mixing chamber. This action creates a vacuum, which pulls the fuel gas into the chamber and ensures thorough mixing. Used for equal gas pressures and is particularly useful for low-pressure fuel gases.
cámara de inyector. Un método de mezclar completamente el gas de combustión y el oxígeno para formar una llama. Oxígeno a alta presión es pasado por una abertura angosta (venturi) a la cámara de mezcla. Está acción hace un vacuo, la cual estira el gas combustible para dentro de la cámara y asegura una mezcla completa. Usada para presiones de gas que son iguales y es particularmente útil para gases combustibles de presión baja.

***inner cone.** The portion of the oxyacetylene flame closest to the welding tip. The primary combustion reaction occurs in the inner cone. The size and color of the cone serve as indicators of the type of flame (carburizing, oxidizing, neutral).
cono interno. La porción de la llama de oxiacetileno más cerca de la punta para soldar. La reacción de combustión principal ocurre en el cono interno. El tamaño y el calor del cono sirve como indicadores del tipo de la llama (carburante, oxidante, neutral).

***intelligent robot.** A robot that can be programmed to make performance choices contingent on sensory inputs.
robot inteligente. Un robot que puede ser programado para hacer preferencias contigentes en sensorios de entrada.

***interface.** A shared boundary. An interface might be a mechanical or an electrical connection between two devices; it might be a portion of computer storage accessed by two or more programs; or it might be a device for communication to or from a human operator.
interface. Un limite repartido. Un interface puede ser una conexión mecánica o eléctrica entre dos aparatos; puede ser una porción de deposito con accesión a dos o más programas; o puede ser un aparato para comunicarse a o con un operador humano.

interpass temperature. In a multipass weld, the temperature of the weld area between weld passes.
temperatura de pasada interna. En una soldadura de pasadas multiples, la temperatura en la área de la soldadura entre pasadas de soldaduras.

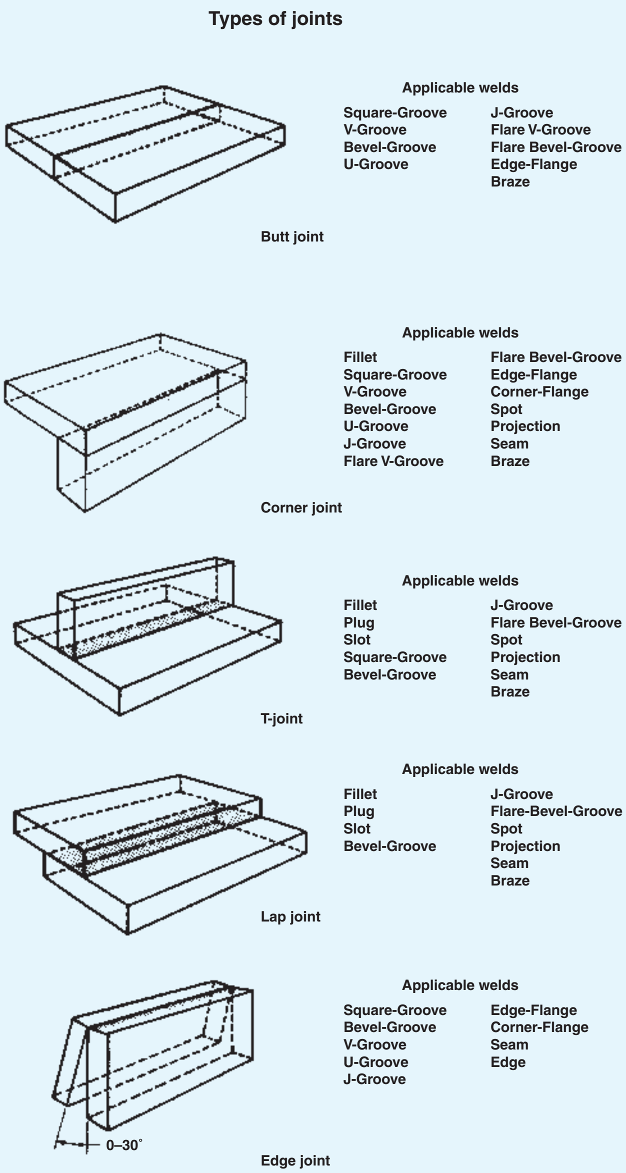
***ionized gas.** A gas that is heated to a point where it becomes conductive. See plasma.
gas ionizado. Gas que pasa a ser conductor una vez que se lo calienta a cierto punto. Ver plasma.

***iron.** An element. Very seldom used in its pure form. The most common element alloyed with iron is carbon.
hierro. Un elemento. Es muy raro que se use en forma pura. El elemento más común del aleado con hierro es carbón.

J

J-groove weld. A type of groove weld.
soldadura con ranura-J. Es un tipo de soldadura de ranura.

joint. The junction of the workpiece(s) that are to be joined or have been joined.
junta. El punto en que se unen dos miembros o las orillas de los miembros que están para unirse o han sido unidos.



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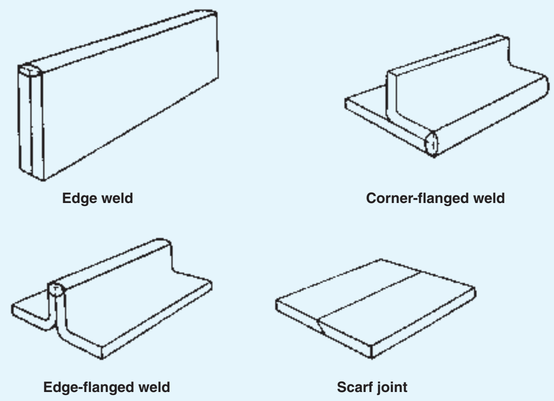

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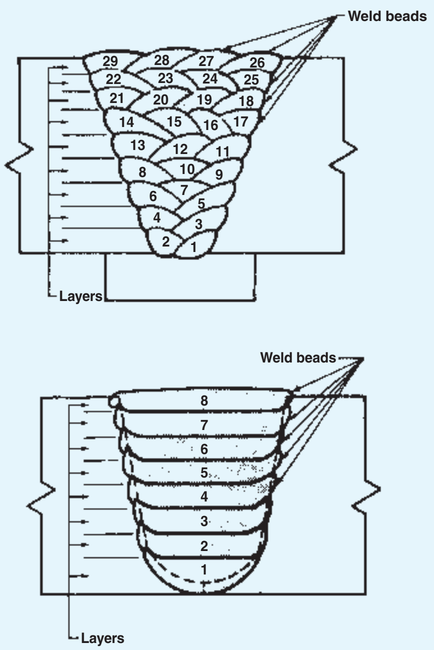
joint buildup sequence. The order in which the weld beads of a multiple pass weld are deposited with respect to the cross section of the joint.
secuencia de formación de una junta. La orden en la cual los cordones de soldadura en una soldadura de pasadas múltiples son depositadas con respecto a la sección transversa de la junta.



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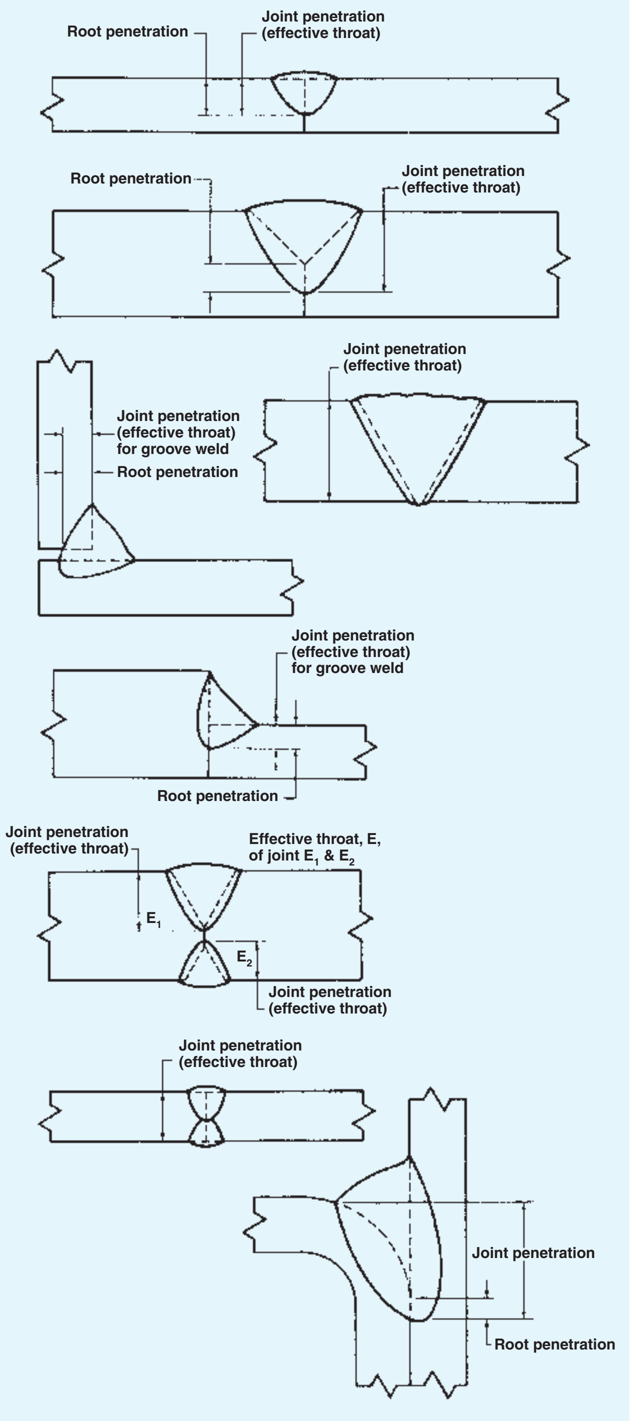
joint clearance. The distance between the faying surfaces of a joint.
despejo de junta. La distancia entre las superficies del empalme de una junta.

joint design. The joint geometry together with the required dimensions of the welded joint.
diseño de junta. La geometría de la junta junto con las dimensiones requeridas de la junta de la soldadura.

joint efficiency. The ratio of the strength of a joint to the strength of the base metal.
eficiencia de junta. La razón de la fuerza de una junta a la fuerza del metal base, expresada en por ciento.

joint geometry. The shape, dimensions, and configuration of a joint prior to welding.
geometría de junta. La figura y dimensión de una junta en sección transversa antes de soldarse.

joint penetration. The distance the weld metal extends from its face into a joint, exclusive of weld reinforcement.
penetración de junta. La distancia del metal soldado que se extiende de su cara hacia adentro de la junta, exclusiva de la soldadura de refuerzo.



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joint root. The portion of a joint to be welded where the members approach closest to each other. In cross section, the joint root may be either a point, a line, or an area.
raíz de junta. Esa porción de una junta que está para soldarse donde los miembros están más cercanos uno del otro. En la sección transversa, la raíz de la junta puede ser una punta, una línea, o una área.

joint type. A weld joint classification based on the five basic arrangements of the component parts such as a butt joint, corner joint, edge joint, lap joint, and tee joint.
tipo de junta. Una clasificación de una junta de soldadura basada en los cinco arreglos del componente de partes como junta a tope, junta en esquina, junta de orilla, junta de solape, y junta en T.

joint welding sequence. See preferred term joint buildup sequence.
secuencia para soldar una junta. Vea el término preferido secuencia de formación de una junta.

***joules.** SI unit of heat.
joules. Unidad de calor del SI.

K

kerf. The width of the cut produced during a cutting process. Refer to drawing for drag.
cortadura. La anchura del corte producido durante un proceso de cortar. Refiérase al dibujo de tiro.

keyhole welding. A technique in which a concentrated heat source penetrates completely through a workpiece, forming a hole at the leading edge of the weld pool. As the heat source progresses, the molten metal fills in behind the hole to form the weld bead.
soldadura con pocillo. Una técnica en la cual una fuente de calor concentrado se penetra completamente a través de la pieza de trabajo, formando un agujero en la orilla del frente del charco de la soldadura. Asi como progresa la potencia de calor, el metal derretido rellena detrás del agujero para formar un cordón de soldadura.

***kindling point.** The lowest temperature at which a material will burn.
punto de ignición. La temperatura más baja la cual un material se puede quemar.

L

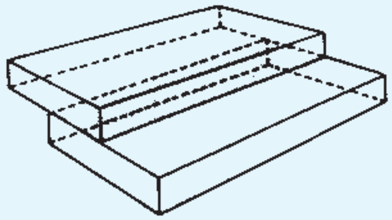
lack of fusion. A nonstandard term for incomplete fusion.
falta de fusión. Un término fuera de norma para fusión incompleta.

lack of penetration. A nonstandard term for incomplete joint penetration.
falta de penetración. Un término fuera de norma para penetración de junta incompleta.

lamellar tear. A subsurface terrace and steplike crack in the base metal with a basic orientation parallel to the wrought surface caused by tensile stresses in the through-thickness direction of the base metals weakened by the presence of small, dispersed, planar-shaped, nonmetallic inclusions parallel to the metal surface.
rasgadura laminar. Una terraza subsuperficie y una grieta como un escalón en el metal base con una orientación paralela a la superficie forjada. Es causada por tensión en la dirección de lo grueso-continuo de los metales de base debilitados por la presencia de pequeños, dispersados, formados como plano, inclusiones no metálicas paralelas a la superficie del metal.

land. See preferred term root face.
hombro. Vea el término preferido cara de raíz.

lap joint. A joint in which the nonbutting ends of one or more workpieces overlap approximately parallel to one another.
junta de solape. Una junta entre dos miembros traslapadas.



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laser beam cutting (LBC). A thermal cutting process severing metal by locally melting or vaporizing it with the heat from a laser beam. The process is used with or without assist gas to aid the removal of molten and vaporized material.
cortes con rayo laser (LBC). Un proceso de cortes termal que separa al metal vaporizado o derretido localmente con el calor de un rayo laser. El proceso es usado sin gas que asiste a remover el material vaporizado o derretido.

***laser beam drilling (LBD).** A thermal cutting process used to produce holes in metal as accurately as if they had been drilled.
perforación por haz de láser (LBD). Proceso de corte térmico usado para producir hoyos de alta precisión en metales como si hubieran sido perforados con taladro.

laser beam welding (LBW). A welding process producing coalescence with the heat from a laser beam impinging on the joint.
soldadura con rayo laser (LBW). Un proceso de soldar que produce coalescencia con calor de un rayo laser al golpear contra la junta.

lattice. An orderly geometric pattern of atoms within a solid metal. The lattice structure is responsible for many of the mechanical properties of the metal.
enrejado. Es una forma geométrica bien arreglada de átomos dentro de un metal sólido. La estructura de enrejado es responsable por muchas propiedades mecánicas del metal.

layer. A stratum of weld metal or surfacing material. The layer may consist of one or more weld beads laid side by side. Refer to drawing for joint buildup sequence.
capa. Un estrato de metal de soldadura o material de superficie. La capa puede consistir de uno o más cordones de soldadura depositados o puestos de lado. Refiérase al dibujo secuencia de formación de una junta.

***leaders and arrows.** Leaders are the straight part and arrows are the pointed end that points to a part to identify it, show the location, and/or are the basis of a welding symbol.
guías y flechas. Las guías son la parte recta y las flechas son el extremo con el que se apunta.

***leak-detecting solution.** A solution, usually soapy water, that is brushed or sprayed on the hose fittings at the regulator and torch to detect gas leaks. If a small leak exists, soap bubbles form.
solución para descubrir escape. Una solución, por lo regular de agua enjabonada, que se acepilla o se rocía sobre las conexiones de las mangueras y los reguladores y antorcha para detectar escape de gas. Si existe un escape pequeño, se forman burbujas de jabón.

leg of a fillet weld. See fillet weld leg.
pierna de soldadura filete. Vea pierna de soldadura filete.

lightly coated electrode, *shielded metal arc welding.* A filler metal electrode consisting of a metal wire with a light coating applied subsequent to the drawing operation, primarily for stabilizing the arc. This is an obsolete or seldom used term.
electrodo con recubrimiento ligero. Un electrodo de metal de aporte consistiendo de un alambre de metal con un recubrimiento ligero aplicado subsecuente a la operación del dibujo, principalmente para estabilizar el arco.

***lime-based flux.** These alkaline fluxes are commonly used on both SMA and FCA welding electrodes.
fundente a base de cal. Estos fundentes alcalinos se usan comúnmente en electrodos SMA y FCA.

***line drop.** The difference between the pressure at the low-pressure gauge and the pressure at the torch; results from the resistance to gas flow offered by the hose and how it is affected by the diameter and length of the hose. The smaller the hose diameter, or the longer the hose, the greater is the line drop.
descenso de línea. La diferencia de la presión en el manómetro de baja presión y la presión en la antorcha; resultados de la resistencia de la corriente del gas causada por la manguera, y como es afectada por el diámetro, y lo largo de la manguera. Si el diámetro de la manguera es más chica o es más larga la manguera, más grande es el descenso.

***liquefied fuel gases.** A gas that is stored under adequate pressure so that it is a liquid.
gases combustibles licuados. Gas almacenado que toma forma líquida debido a la presión de almacenamiento.

***liquid-solid phase bonding process.** Soldering or brazing where the filler metal is melted (liquid) and the base material does not melt (solid); the phase is the state at which bonding takes place between the solid base material and liquid filler metal. There is no alloying of the base metal.
proceso de ligación de fase líquido-sólido. Soldando con soldadura blanda o soldadura fuerte donde el metal de relleno se derrite (líquido) y el material base no se derrite (sólido); la fase es el estado la cual el ligamento se lleva a cabo entre el material base sólido y el metal de relleno (líquido). No se mezcla con el metal base.

liquidus. The lowest temperature at which a metal is completely liquid.
liquidus. La temperatura más baja en la cual un metal o un aleado es completamente líquido.

local preheating. Preheating a specific portion of a structure.
precalentamiento local. El precalentamiento de una porción especificada de un estructura.

local stress relief heat treatment. Stress relief heat treatment of a specific portion of a structure.
tratamiento de calor para relevar la tensión local. Un tratamiento de calor el cual releva la tensión de una porción especificada de una estructura.

longitudinal sequence. The order in which the weld passes of a continuous weld are made in respect to its length. See also backstep sequence.
secuencia longitudinal. La orden en que las pasadas de un soldadura continua son hechas en respecto a su longitud. Vea también secuencia a la inversa.

***low-fuming alloys.** As it relates to brazing filler rods it indicates that there is enough deoxidizers in the alloy to reduce the problem of zinc forming oxides during torch brazing.
aleación poco humeante. En relación a barras de relleno de soldadura fuerte. Indica que hay suficientes desoxidantes en la aleación para reducir el problema de que el zinc forme óxidos durante la soldadura fuerte con antorcha.

M

***machine operation.** Welding operations are performed automatically under the observation and correction of the operator.
operación de máquina. Operaciones de soldadura son ejecutadas automáticamente bajo la observación y corrección del operador.

machine welding. Welding with equipment that performs the welding operation under the constant observation and control of a welding operator. The equipment may or may not perform the loading and unloading of the work. See also automatic welding.
máquina para soldadura. Soldadura con equipo que ejecutan la operación de soldadura bajo la observación constante de un operador de soldadura. El equipo pueda o no ejecutar el cargar o descargar del trabajo. Vea también soldadura automática.

***macro structure.** A structure large enough to be seen with the naked eye or low magnification, usually under 30 power.
estructura macro. Una estructura suficientemente grande que puede verse con el puro ojo o con un amplificador de aumento bajo, regularmente abajo de poder 30.

macroetch test. A test in which a specimen is prepared with a fine finish, etched, and examined under low magnification.
prueba con grabado al agua fuerte y examinado por magnificación. Una prueba en una probeta preparada con acabado fino, grabada al agua fuerte, y examinado debajo de un amplificador de aumento bajo.

***magnetic flux lines.** Parallel lines of force that always go from the north pole to the south pole in a magnet, and surround a DC current–carrying wire.
líneas magnéticas de flujo. Líneas paralelas de fuerza que siempre van del polo norte al polo sur en un magneto, y rodea un alambre que lleva corriente DC.

***malleable cast iron.** See cast iron.
acero vaciado maleable. Ver acero vaciado.

manifold. A multiple header for interconnection of gas or fluid sources with distribution points.
conexión múltiple. Una tuberia con conexiones múltiples que sirve como fuente de gas o flúido con puntos de distribución.

***manifold system.** Used when there are a number of workstations or a high volume of gas is required. A piping system that allows several oxygen and fuel-gas cylinders to be connected to several welding stations. Normally regulators are provided at the manifold and at the stations to provide control of the oxygen and fuel-gas pressures. Safety features such as reverse flow valves, flashback arrestors, and back pressure release must be provided at the manifold.
sistema de conexiones múltiples. Usado cuando hay un número de estaciones de trabajo o cuando se requiere un alto volumen de gas. Un sistema de tubos que permite que se conecten varios cilindros de oxígeno y gas combustible a varias estaciones de soldadura. Normalmente se usan reguladores en el tubo de conexiones múltiples y en las estaciones para mantener el control de la presión del oxígeno y el gas combustible. Normas de seguridad como válvulas de retención, protector de agua contra retroceso de llama, y escape de presión deben usarse en el tubo de conexiones múltiples.

***manipulator.** A mechanism, usually consisting of a series of segments, joined or sliding relative to one another for the purpose of grasping and moving objects, usually in several degrees of freedom. It may be remotely controlled by a computer or by a human.
manipulador. Un mecanismo, que consiste regularmente de una serie de segmentos unidos o corredizos con relación del uno al otro con el propósito de que agarre y mueva objetos, por lo regular en varios grados de libertad. Puede ser controlado remotamente por una computadora o un humano.

***manual operation.** The entire welding process is manipulated by the welding operator.
operación manual. Todo el proceso de soldadura es manipulado por un operador de soldadura.

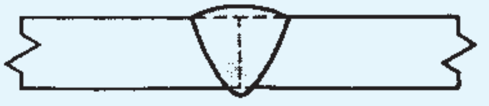
manual welding. Welding with the torch, gun, or electrode holder held and manipulated by hand. Variations of this term are *manual brazing, manual soldering, manual thermal cutting,* and *manual thermal spraying.*
soldadura manual. Soldando con la antorcha, pistola, porta electrodo detenido y manipulado por la mano. Variaciones de este término son *soldadura fuerte manual, soldadura blanda manual, cortes termal manual,* y *rociado termal manual.*

***MAPP.** One manufacturer's trade name for a specific stabilized, liquefied MPS mixture. MAPP® has a distinctive odor, which makes it easy to detect; used for welding and cutting. See also methylacetylene-propadiene (MPS).
MAPP. Un nombre comercial de un fabricante para una específica estabilizada, licuada, mezcla MPS. MAPP tiene un olor distintivo, el cual es muy fácil de descubrir; es usado para cortes y soldaduras. Vea también metilacetileno y propadieno.

***martensite.** A very hard and brittle solid-solution phase that is found in medium- and high-carbon steels.
martensita. Una solución sólida con un aspecto muy duro y quebradizo que se encuentra en aceros medianos y de alto carbón.

***mechanical testing (DT).** See destructive testing.
prueba mecánica (DT). Ver prueba destructiva.

melt through. Complete joint penetration for a joint welded from one side. Visible root reinforcement is produced.
derretir de un lado a otro. Una junta con penetración completa para una junta que está soldada de un lado. Refuerzo de raíz visible es producido.



Melt through

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meltback time. The time interval at the end of crater fill time to arc outage during which electrode feed is stopped. Arc voltage

and arc length increase and current decreases to zero to prevent the electrode from freezing in the weld deposit.
tiempo de refundición. El tiempo de intervalo al fin del tiempo en que se llena el crater hasta que se apaga el arco durante el cual el alimento del electrodo se detiene. El voltaje del arco y lo largo del arco aumenta y la corriente empieza a desminuir hasta llegar a cero para prevenir la congelación del electrodo en el deposito de la soldadura.

melting range. The temperature range between solidus and liquidus.
variación de derretimiento. La variación de temperatura entre solidus y liquidus.

melting rate. The weight or length of electrode, wire, rod, or powder, melted in a unit of time.
cantidad de derretimiento. El peso o lo largo de un electrodo, alambre, varilla, o polvo derretido en una unidad de tiempo.

***metal.** An opaque, lustrous, elemental, chemical substance that is a good conductor of heat and electricity, usually malleable, ductile, and more dense than other elemental substances.
metal. Una opaca, brillante, elemental, substancia química que es una buena conductora de calor y electricidad, por lo regular es maleable, ductil, y es más densa que otras substancias elementales.

metal arc cutting (MAC). Any of a group of arc cutting processes that sever metals by melting them with the heat of an arc between a metal electrode and the base metal. See also shielded metal arc cutting and gas metal arc cutting.
cortes de metal con arco (MAC). Cualquiera de un grupo de procesos de cortes con arco que corta metales derritiéndolos con el calor de un arco entre un electrodo de metal y el metal base. Vea también cortes de arco metálico protegido y cortes de arco metálico con gas.

metal cored electrode. A composite tubular filler metal electrode consisting of a metal sheath and a core of various powdered materials, producing no more than slag islands on the face of a weld bead. External shielding may be required.
electrodo de metal de núcleo. Un electrodo de metal para rellenar tubular compuesto consistiendo de una envoltura de metal y núcleo de varios materiales en polvo, que producen nada más que islas de escoria en la cara del cordón de soldadura. Protección externa puede ser requerida.

metal electrode. A filler or nonfiller metal electrode used in arc welding or cutting that consists of a metal wire or rod manufactured by any method and either bare or covered.
electrodo de metal. Un electrodo de metal que se usa para rellenar o para no rellenar la soldadura de arco o para cortar, que consiste de un alambre de metal o varilla que ha sido fabricada por cualquier método ya sea liso o cubierto con un cubierto o revestimiento propio.

***metallurgy.** The scientific study of metals.
metalurgia. Estudio científico de los metales.

***methylacetylene-propadiene (MPS).** A family of fuel gases that are mixtures of two or more gases (propane, butane, butadiene, methylacetylene, and propadiene). The neutral flame temperature is approximately 5031°F (2927°C), depending upon the actual gas mixture. MPS is used for oxyfuel cutting, heating, brazing, and metallizing; rarely used for welding.
metilacetileno y propadieno (MPS). Una familia de gases de combustión que son mezclas de dos o más gases (propano, butano, butadiano, metilacetileno, propadieno). La temperatura de la llama natural es aproximadamente 5031°F (2927°C), dependiendo de la mezcla actual del gas. MPS es usado como gas de combustión para cortar, calentar, soldadura fuerte, y metalizar; es muy raro que se use para soldar.

***micro structure.** A structure that is visible only with high magnification or with the aid of a microscope.
estructura micronesia. Una estructura que es visible solamente con un amplificador de poder muy alto o con la ayuda de un microscopio.

***microcomputer.** A computer that uses a microprocessor as its basic element.
computadora micronesia. Una computadora que usa un procesor micronesio como su elemento básico.

microetch test. A test in which the specimen is prepared with a polished finish, etched, and examined under high magnification.
prueba con grabado al agua fuerte y examinada por un amplificador de alto poder. Una prueba en una probeta preparada con acabado fino, grabada al agua fuerte y examinado bajo un amplíficador de alto poder.

***microprocessor.** The principal processing element of a microcomputer, made as a single, integrated circuit.
procesor micronesio. El elemento principal de un procedimiento de una computadora micronesia, hecha con un solo circuito integrado.

mineral-based electrode fluxes. Fluxes that use inorganic compounds such as the rutile-based flux (titanium dioxide, TiO_2). These mineral compounds do not contain hydrogen, and electrodes that use these fluxes are often referred to as low hydrogen electrodes. Less smoke is generated with this welding electrode than with cellulose-based fluxes, but a thicker slag layer is deposited on the weld. E7018 is an example of an electrode that uses this type of flux.
fundentes para electrodos de base mineral. Fundentes que usan compuestos inorgánicos, como por ejemplo, el fundente a base de rutilo (bióxido de titanio, TiO_2). Estos compuestos minerales no contienen hidrógeno, y a los electrodos que usan estos fundentes se los llama con frecuencia electrodos de bajo hidrógeno. En la soldadura con electrodos se producen menos humos que en la que se realiza con fundentes celulósicos, pero se deposita una capa de escoria más gruesa en la soldadura. El E7018 es un ejemplo de un electrodo que usa este tipo de fundente.

mixing chamber. That part of a welding or cutting torch in which a fuel gas and oxygen are mixed.
cámara mezcladora. Esa parte de una antorcha para soldar y cortar por la cual el gas combustible y el oxígeno son mezclados.

mold. A high-temperature container into which liquid metal from the thermite welding process is poured and held until it cools and hardens into the container's interior shape.
molde. un contenedor de alta temperatura en el cual se vierte y se mantiene metal líquido del proceso de soldadura con termita hasta que éste se enfríe y se solidifique tomando la forma interior del contenedor.

molecular hydrogen. A bonded pair of hydrogen atoms (H_2). This is the configuration that all hydrogen atoms try to form.
hidrógeno molecular. Un par de átomos de hidrógeno (H_2) unidos. Ésta es la configuración que tratan de formar todos los átomos de hidrógeno.

molten weld pool. The liquid state of a weld prior to solidification as weld material.
charco de soldadura derretido. El estado líquido de una soldadura antes de solidificarse como material de soldadura.

***multipass weld.** A weld requiring more than one pass to ensure complete and satisfactory joining of the metal pieces.
soldadura de pasadas múltiples. Una soldadura que requiere más de una pasada para asegurar una completa y satisfactoria unión de las piezas de metal.

N

***natural ventilation.** Ventilation usually resulting from the heat-generated convection currents that cause welding fumes to rise.
ventilación natural. Ventilación que por lo general resulta de corrientes de convección generadas por el calor que causa la elevación del humo de la soldadura.

***needle-like** (acicular structure). See acicular structure.
con forma de aguja (estructura acicular). Ver estructura acicular.

neutral flame. An oxyfuel gas flame that is neither oxidizing nor reducing.
llama neutral. Una llama de gas oxicombustible que no tiene características de oxidación ni de reducción. Refiérase al dibujo para cono.

***noble inert gas.** See preferred term inert gas.
gas inerte noble. Ver el término preferido gas inerte.

nonconsumable electrode. An electrode that does not provide filler metal.
electrodo no consumible. Un electrodo que no provee metal de relleno.

noncorrosive flux, *brazing and soldering*. A soldering flux that in either its original or its residual form does not chemically attack the base metal.
flujo no corrosivo, *soldadura fuerte y soldadura*. Un flujo para soldadura blanda que ni en su forma original ni en su forma restante químicamente ataca el metal base. Regularmente es compuesto de materiales de colofonia o resino de base.

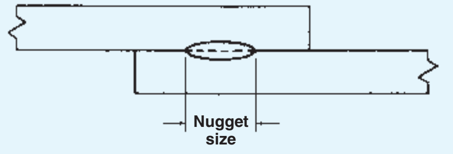
***nondestructive testing (NDT).** Methods that do not alter or damage the weld being examined; used to locate both surface and internal defects. Methods include visual inspection, penetrant inspection, magnetic particle inspection, radiographic inspection, and ultrasonic inspection.
pruebas no destructivas (NDT). Métodos que no alteran ni dañan la soldadura que se está examinando. Se usa para encontrar ambos defectos internos y de superficie. Incluye métodos como inspección visual, inspección penetrante, inspección de partículas magnéticas, inspección de radiografía, inspección ultrasónica.

nontransferred arc. An arc established between the electrode and the constricting nozzle of the plasma arc torch or thermal spraying. The workpiece is not in the electrical circuit. See also transferred arc.
arco no transferible. Un arco establecido entre el electrodo y la boquilla constrictiva de la antorcha del arco de plasma o pistola termal para rociar. La pieza de trabajo no está en el circuito eléctrico. Vea también arco transferido.

nozzle. A device that directs shielding media.
boquilla. Un aparato que dirige el medio de protección.

nugget. The weld metal joining the workpieces in spot, seam, and projection welds.
botón. El metal de soldadura que une a las piezas de trabajo en soldadura de puntos, costura, y proyección de soldaduras.

nugget size. A nonstandard term when used for projection weld size, resistance weld size, or seam weld size.
tamaño del botón. El diámetro o lo ancho del botón medido en el plano del interfaze entre las piezas unidas.



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O

***object line.** Lines on a drawing that show the edge of an object, the intersection of surfaces that form corners or edges, and the extent of a curved surface, such as the sides of a cylinder.
línea de objeto. Líneas de un dibujo que muestran el borde de un objeto, la intersección de las superficies que forman las esquinas o los bordes y la extensión de una superficie curva, como los lados de un cilindro.

open circuit voltage. The voltage between the output terminals of the power source when the rated primary voltage is applied and no current is flowing in the secondary circuit.
voltaje de circuito abierto. El voltaje entre los terminales de salida de una fuente de poder cuando la corriente no está corriendo a la antorcha o pistola.

open-root joint. An unwelded joint without backing or consumable insert.
junta de raíz abierta. Una junta que no está para soldarse sin respaldo o inserto consumible.

***operating voltage.** It is the actual voltage across the arc or closed-circuit voltage.
tensión operativa. Tensión real en el arco o tensión de circuito cerrado.

orifice. See constricting orifice.
orifice. Vea orifice de constreñimiento.

orifice gas. The gas that is directed into the plasma arc torch or thermal spraying gun to surround the electrode. It becomes ionized in the arc to form the arc plasma and issues from the constricting orifice of the nozzle as a plasma jet.
gas para orifice. El gas que es dirigido dentro de la antorcha de plasma o la pistola de rociado termal para rodear el electrodo. Se vuelve ionizado dentro del arco para formar el arco de plasma y sale de la orifice de constreñimiento a la boquilla como chorro de plasma.

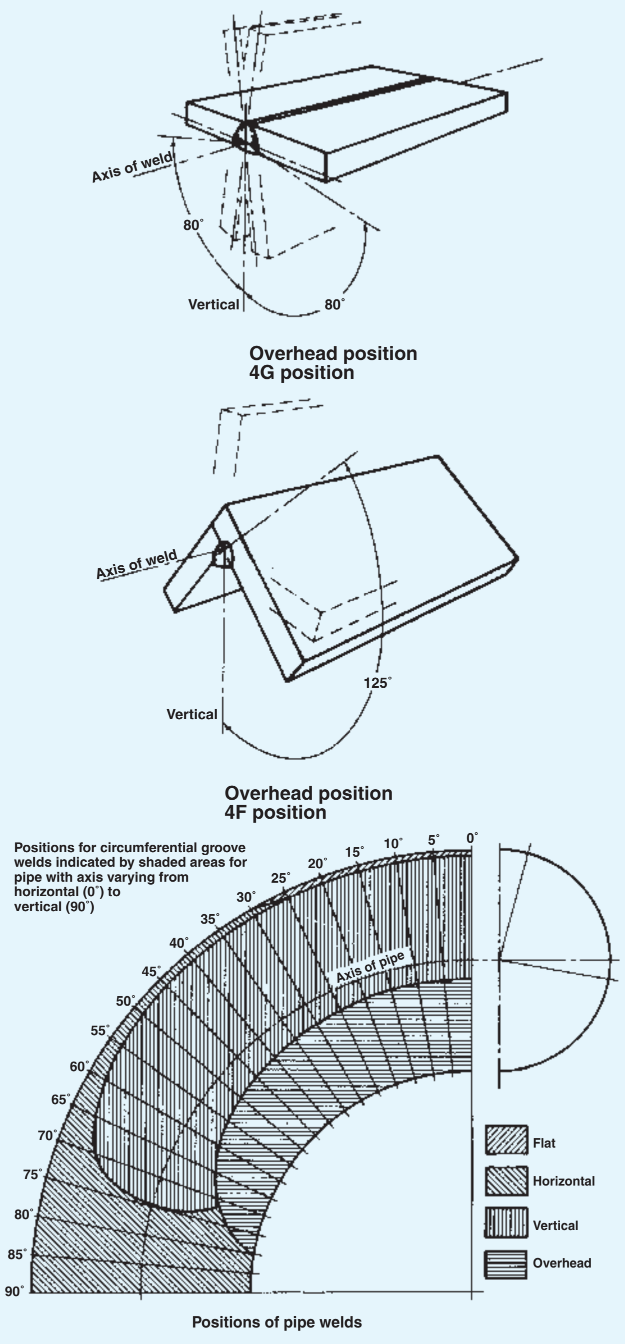
orifice throat length. The length of the constricting orifice in the plasma arc torch or thermal spraying gun.
largo de garganta del orifice. Lo largo de la orifice constreñida en la antorcha de plasma o en la pistola de plasma para rociar.

***out-of-position welding.** Any welding position other than the flat position; includes vertical, horizontal, and overhead positions.
soldadura fuera de posición. Cualquier posición de soldadura menos la de la posición plana; incluye vertical, horizontal, y posiciones de sobrecabeza.

***outer envelope.** The outer boundary of the oxyacetylene flame. The secondary combustion reaction occurs in the outer envelope.
envoltura externa. El límite de afuera de la llama de oxiacetileno. La reacción de la combustión secundaria ocurre en la envoltura externa.

***outside corner joint.** See joint.
junta de esquina externa. Ver junta.

overhead position. The position in which welding is performed from the underside of the joint.
posición de sobrecabeza. La posición en la cual se hace la soldadura por el lado de abajo de la junta.



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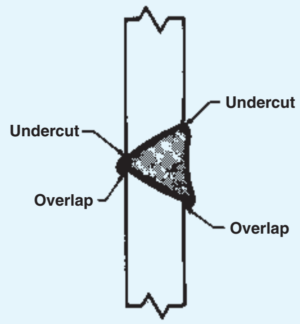
overlap. The protrusion of weld metal beyond the toe, face, or root of the weld; in resistance seam welding, the area in the preceding weld remelted by the succeeding weld.
traslapo. El metal de la soldadura que sobresale más allá del pie, cara, o de la raíz de una soldadura; en soldaduras de costuras por resistencia, la área de la soldadura anterior se rederrite por la soldadura subsiguiente.

***oxide layer.** A layer of oxidized metal on the surface, on steel it can be called rust.
capa de óxido. Capa de metal oxidado que está sobre la superficie. En el acero se puede denominar herrumbre.



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oxidizing flame. An oxyfuel gas flame in which there is an excess of oxygen, resulting in an oxygen-rich zone extending around and beyond the cone.
llama oxidante. Una llama de gas oxicombustible en la cual hay un exceso de oxígeno, resultando en una zona rica de oxígeno extendiéndose alrededor y más allá del cono.

oxyacetylene cutting (OFC-A). An oxyfuel cutting process variation employing acetylene as the gas.
cortes con oxiacetileno (OFC-A). Un proceso de cortes con gas con variación que usa acetileno como gas de combustión.

***oxyacetylene hand torch.** Most commonly used oxyfuel gas cutting torch; may be a cutting torch only or a combination welding and cutting torch set. On the combination set different tips can be attached to the same torch body. The torch mixes the oxygen and fuel gas and directs the mixture to the tip. The torch can be an equal pressure type (equal pressures of oxygen and fuel gas) or an injector type (equal pressures of high-pressure oxygen and low-pressure fuel gas).
antorcha de mano oxiacetileno. La antorcha de gas oxicombustible es la que se usa más frecuentemente; puede ser una antorcha para hacer cortes solamente o una combinación de un juego de antorcha para soldar y hacer cortes. En el juego de combinación diferentes puntas pueden ser conectadas al mismo mango de la antorcha. La antorcha mezcla el oxígeno y gas combustible y dirige la mezcla a la punta. La antorcha puede ser de tipo de presión igual (presiones iguales de oxígeno y gas combustible) o de tipo inyector (presiones iguales de oxígeno de alta presión y baja presión de gas combustible).

oxyacetylene welding (OAW). An oxyfuel gas welding process employing acetylene as the fuel gas. The process is used without the application of pressure.
soldadura con oxiacetileno (OAW). Un proceso de soldadura de gas oxicombustible que usa acetileno con gas de combustión. El proceso se usa sin aplicación de presión.

***oxyfuel flame.** A flame resulting from the combustion of oxygen mixed with a fuel gas. This intense flame is applied to two pieces of metal to cause them to melt to form weld pools. When the edges of the weld pools run together and fuse, the two pieces of metal are joined.
llama oxicombustible. Una llama que resulta de una combustión de oxígeno mezclado con gas combustible. Está llama intensa es aplicada a dos piezas de metal para hacer que se derritan para formar charcos de soldadura. Cuando las orillas de los charcos de soldadura se juntan y se derriten, las dos piezas de metal se unen.

***oxyfuel gas.** A general term covering all the different fuel gases such as acetylene, MAPP®, natural gas, propane, hydrogen, etc., that can be used with oxygen.
gas oxicombustible. Término general que cubre todos los diferentes gases combustibles como el acetileno, MAPP, gas natural, propano, hidrógeno, etc., que se pueden utilizar con el oxígeno.

oxyfuel gas cutting (OFC). A group of oxygen cutting processes that uses heat from an oxyfuel gas flame. See also oxygen cutting, oxyacetylene cutting, oxyhydrogen cutting, and oxypropane cutting.
gas para cortar oxicombustible (OFC). Un grupo de procesos para cortar con oxígeno que usa calor de una llama de gas oxicombustible. Vea también cortes con oxigeno, cortes con oxiacetileno, cortes con oxihidrógeno, y cortes con oxipropano.

oxyfuel gas cutting torch. A device used for directing the preheating flame produced by the controlled combustion of fuel gases and to direct and control the cutting oxygen.
antorcha para cortes de gas oxicombustible. Un aparato que se usa para dirigir la llama precalentada producida por la combustión controlada de los gases de combustión y para dirigir y controlar el oxígeno para cortar.

oxyfuel gas welding (OFW). A group of welding processes producing coalescence of workpieces by heating them with an oxyfuel gas flame. The processes are used with or without the application of pressure and with or without filler metal.
soldadura con gas oxicombustible (OFW). Un grupo de procesos de soldadura que produce coalescencia de las piezas de trabajo calentándolas con una llama de gas oxicombustible. Los procesos son usados sin la aplicación de presión y con o sin el metal para rellenar.

oxyfuel gas welding torch. A device used in oxyfuel gas welding, torch brazing, and torch soldering for directing the heating flame produced by the controlled combustion of fuel gases.
antorcha para soldar con gas oxicombustible. Un aparato que se usa para soldar con gas oxicombustible, soldadura fuerte con antorcha, soldadura blanda con antorcha y para dirigir la llama calentada producida por combustión controlada de gases de combustión.

oxygen arc cutting (OAC). An oxygen cutting process using an arc between the workpiece and a consumable tubular electrode, through which oxygen is directed to the workpiece.
cortes de oxígeno con arco (OAC). Es un proceso de cortar con oxígeno que usa un arco entre la pieza de trabajo y un electrodo tubular consumible, por el cual el oxígeno es dirigido a la pieza de trabajo.

oxygen cutting (OC). A group of thermal cutting processes severing or removing metal by means of the chemical reaction between oxygen and the base metal at elevated temperature. The necessary temperature is maintained by the heat from an arc, an oxyfuel gas maintained by the heat from an arc, an oxyfuel gas flame, or other sources. See also oxyfuel gas cutting.
cortes con oxígeno (OC). Un grupo de procesos termales que corta y quita el metal por medio de una reacción química entre el oxígeno y el metal base a una temperatura elevada. La temperatura necesaria es mantenida por el calor del arco, un gas oxicombustible mantenido por el calor del arco, una llama de gas oxicombustible, o de otras fuentes. Vea también gas para cortar oxicombustible.

oxygen gouging. Thermal gouging using an oxygen cutting process variation to form a bevel or groove.
escopleando con la gubia con oxígeno. Gubia termal que usa un proceso de variación de corte con oxígeno para formar un bisel o ranura.

oxygen lance. A length of pipe used to convey oxygen to the point of cutting in oxygen lance cutting.
lanza de oxígeno. Un tramo de tubo usado para conducir oxígeno al punto de cortar en cortes con lanza de oxígeno.

oxygen lance cutting (OLC). An oxygen cutting process employing oxygen supplied through a consumable lance. The preheat to start the cutting is obtained by other means.
cortes con lanza de oxígeno (OLC). Un proceso de cortar con oxígeno que usa oxígeno surtido por una lanza consumible. El precalentamiento para empezar a cortar es obtenido por otros medios.

oxyhydrogen cutting (OFC-H). An oxyfuel gas cutting process variation that uses hydrogen as the fuel gas.
cortes con oxihidrógeno (OFC-H). Un proceso de cortar de gas oxicombustible con variación que usa hidrógeno como gas combustible.

***oxyhydrogen flame.** A specific flame resulting from the combustion of oxygen and hydrogen; consists of primary combustion region only; used for welding and cutting.
llama oxihidrógeno. Una llama específica que resulta de la combustión del oxígeno e hidrógeno; consiste solamente de la región de combustión primaria; usada para cortar y soldar.

oxyhydrogen welding (OHW). An oxyfuel gas welding process that uses hydrogen as the fuel gas. The process is used without the application of pressure.
soldadura oxihidrógeno (OHW). Un proceso de soldar con gas oxicombustible que usa hidrógeno como gas de combustible. El proceso se usa sin la aplicación de presión.

oxypropane cutting (OFC-P). An oxyfuel gas cutting process variation employing propane as the fuel gas.
cortes con oxipropano (OFC-P). Un proceso de cortar con gas combustible con variación que usa propano como gas combustible.

P

parent metal. See preferred term base metal.
metal de origen. Vea término preferido metal base.

***paste range.** The temperature range of soldering and brazing filler metal alloys in which the metal is partly solid and partly liquid as it is heated or cooled.
grados de la pasta. Los grados de la temperatura del metal para rellenar aleados para soldadura blanda o soldadura fuerte cuando se calienta o se enfria.

***pearlite.** A two-phased lamellar iron carbon crystalline structure that forms during slow cooling.
perlita. Estructura cristalina de hierro y carbono laminar de dos fases que se forma durante el enfriamiento lento.

peel test. A destructive method of inspection that mechanically separates a lap joint by peeling.
prueba por pelar. Un método de inspección destructivo de pelar que separa mecánicamente una junta de solape.

peening. The mechanical working of metals using impact, often with a ball peen hammer.
martillazos (con martillo de bola). Metales que se trabajan mecánicamente con golpes de impacto.

***penetration.** The depth into the base metal (from the surface) that the weld metal extends, excluding any reinforcement.
penetración. La profundidad de adentro del metal base (de la superficie) que el metal de soldadura se extiende, excluyendo cualquier refuerzo.

percussion welding (PEW). A welding process that produces coalescence with an arc resulting from a rapid discharge of electrical energy. Pressure is applied percussively during or immediately following the electrical discharge.
soldadura a percusión (PEW). Un proceso de soldadura que produce coalescencia con un arco resultando de una descarga rápida de energia. Presión es aplicada a percusión durante o inmediatamente después de la descarga eléctrica.

***phantom lines.** Lines on a drawing that show an alternate position of a moving part or the extent of motion, such as the on/off position of a light switch. They can also be used as a place holder for a part that will be added later.
líneas fantasmas. Líneas de un dibujo que muestran una posición alternativa de una pieza móvil o el rango del movimiento de ésta, como las posiciones de encendido/apagado de un interruptor de luz. También se pueden usar como marcador de posición para una pieza que se añadirá posteriormente.

***phase diagrams.** Provide information on the crystalline constituents of metal alloys at different temperatures in three different phases: pure metal, solid solutions of two or more metals, and intermetallic compounds.
diagramas de equilibrio. Proporciona información en los constituyentes cristalinos de metales aleados a diferentes temperaturas en tres aspectos: metal puro, soluciones sólidas de dos o más metales, y mezclas intermetálicas.

***pick-and-place robot.** A simple robot, often with only two or three degrees of freedom, which transfers items from place to place by means of point-to-point moves. Little or no trajectory control is available. Often referred to as a “bank-bank” robot.
robot de escoger y atar. Un robot simple, frecuentemente con solo dos o tres grados de libertad, el cual traslada artículos de un lugar a otro por medio de movidas de punto a punto. Un poco o nada de control trayectoria es utilizado. A veces es referido como un “banco-banco” robot.

***pictorial drawings.** A type of mechanical drawing that represents an object as a picture.
dibujo ilustrativo. Tipo de dibujo mecánico que representa un objeto como una ilustración.

pilot arc. A low-current arc between the electrode and the constricting nozzle of the plasma arc torch to ionize the gas and facilitate the start of the welding arc.
piloto del arco. Un arco de corriente baja en medio del electrodo y la boquilla constreñida de la antorcha de arco de plasma para ionizar el gas y facilitar el arranque del arco para soldar.

***pitch.** The angular rotation of a moving body about an axis perpendicular to its direction of motion and in the same plane as its top side.
grado de inclinación. La rotación angular de un cuerpo en movimiento alrededor de un eje perpendicular a su dirección y en el mismo plano como el del lado de arriba.

***plain carbon steels.** See carbon steel.
acero de carbón puro. Ver acero al carbono

plasma. A gas that has been heated to an at least partially ionized condition, enabling it to conduct an electric current.
plasma. Un gas que ha sido calentado a lo menos parcialmente a una condicón ionizada permitiendo que conduzca una corriente eléctrica.

***plasma arc.** See plasma.
arco de plasma. Ver plasma.

plasma arc cutting (PAC). An arc cutting process employing a constricted arc and removes the molten metal with a high-velocity jet of ionized gas issuing from the constricting orifice.
cortes con arco de plasma (PAC). Un proceso de cortar con el arco que usa un arco constreñido y quita el metal derretido con un chorro de alta velocidad de gas ionizado que sale de la orifice constringente.

***plasma arc gouging.** See plasma arc cutting.
gubiadura con arco de plasma. Ver cortes con arco de plasma.

plasma arc welding (PAW). An arc welding process employing a constricted arc between a nonconsumable electrode and the weld pool (transferred arc) or between the electrode and the constricting nozzle (nontransferred arc). Shielding is obtained from the ionized gas issuing from the torch, which may be supplemented by an auxiliary source of shielding gas. The process is used without the application of pressure.
soldadura con arco de plasma (PAW). Un proceso de soldadura de arco que usa un arco constreñido entre un electrodo que no se consume y el charco de la soldadura (arco transferido) o entre el electrodo y la lanza constreñida (arco no transferido). La protección es obtenida del gas ionizado que sale de la antorcha, el cual puede ser suplementado por una fuente auxiliar de gas para protección. El proceso es usado sin la aplicación de presión.

plug weld. A weld made in a circular hole in one member of a joint fusing that member to another member. A fillet-welded hole should not be construed as conforming to this definition.
soldadura de tapón. Una soldadura que se hace en un agujero circular en un miembro de una junta uniendo ese miembro con otro miembro. Un agujero de soldadura de filete no debe ser interpretado como confirmación de está definición.

***point-to-point control.** A control scheme whereby the inputs or commands specify only a limited number of points along a desired path of motion. The control system determines the intervening path segments.
control de punto a punto. Una esquema de control con que las entradas o las ordenes especifican solamente un número limitado de puntos a lo largo de la senda de moción deseada. El sistema de control determina el intervenio de los segmentos de la senda.

porosity. Cavity-type discontinuities formed by gas entrapment during solidification or in a thermal spray deposit.
porosidad. Un tipo de cavidad de desuniones formadas por gas atrapado durante la solidificación o en un deposito rociado termal.

postflow time. The time interval from current shutoff to shielding gas and/or cooling water shutoff.
tiempo de poscorriente. El intervalo de tiempo de cuando se cierra la corriente a cuando se cierra el gas de protección y o cuando se cierra el agua para enfriar.

postheat current (resistance welding). The current through the welding circuit during postheat time in resistance welding.
corriente de poscalentamiento (soldadura de resistencia). La corriente que va de un lado a otro del circuito durante el tiempo de poscalentamiento en la soldadura de resistencia.

postheat time (resistance welding). The time from the end of weld heat time to the end of weld time. Refer to drawing for downslope time.
tiempo de poscalentamiento (soldadura de resistencia). El tiempo del fin del calor de la soldadura al tiempo al fin del tiempo de la soldadura. Refiérase al dibujo de tiempo de cadía del pendiente.

postheating. The application of heat to an assembly after welding, brazing, soldering, thermal spraying, or thermal cutting. See also postweld heat treatment.
poscalentamiento. La aplicación de calor a una asamblea después de la soldadura, soldadura fuerte, soldadura blanda, rociado termal o corte termal. Vea también tratamiento de calor postsoldadura.

***postpurge.** Once welding current has stopped in gas tungsten arc welding, this is the time during which the gas continues to flow to protect the molten pool and the tungsten electrode as cooling takes place to a temperature at which they will not oxidize rapidly.
pospurgante. Cuando la corriente de soldar se ha dentenido en la soldadura de arco gas tungsteno, este es el tiempo durante en que el gas continua a salir para proteger el charco de soldadura derretido y el electrodo de tungsteno se enfrian a una temperatura donde no se oxidan rápidamente.

postweld heat treatment. Any heat treatment subsequent to welding.
tratamiento de calor postsoldadura. Cualquier tratamiento de calor subsiguiente a la soldadura.

powder flame spraying. A thermal spraying process variation in which the material to be sprayed is in powder form. See also flame spraying (FLSP).
rociado de polvo con llama. Un proceso termal para rociar con variación el cual el material que está para rociar se está en forma de polvo. Vea también rociado a llama.

power source. An apparatus for supplying current and voltage suitable for welding, thermal cutting, or thermal spraying.
fuente de poder. Un aparato para surtir corriente y voltaje conveniente para soldar, para hacer cortes termales, o rociado termal.

power supply. Nonstandard term for power source.
fuente de alimentación. Término no estandarizado de fuente de poder.

***preflow.** Shielding gas that flows before the GTA welding current starts to force the air away from the arc zone, which protects both the hot tungsten and weld from atmospheric contamination when welding starts.
preflujo. Gas protector que fluye antes de que la corriente de soldadura GTA corra para forzar el aire a salir de la zona del arco. El gas protege tanto el tungsteno caliente como la soldadura de la contaminación atmosférica una vez iniciada la soldadura.

preheat. The heat applied to the base metal or substrate to attain and maintain preheat temperature.
precalentamiento. El calor aplicado al metal base o substrato para obtener y mantener temperatura de precalentamiento.

***preheat flame.** Brings the temperature of the metal to be cut above its kindling point, after which the high-pressure oxygen stream causes rapid oxidation of the metal to perform the cutting.
llama para precalentamiento. Sube la temperatura del metal que está para cortarse a una temperatura de encendimiento, después que la corriente del oxígeno de alta presión cause una oxidación rápida del metal para hacer el corte.

***preheat holes.** The cutting tip has a central hole through which the oxygen flows. Surrounding this central hole are a number of other holes called preheat holes. The differences in the type or number of preheat holes determine the type of fuel gas to be used in the tip.
agujeros para precalentamiento. La boquilla para cortar tiene un agujero central por donde corre el oxígeno. Rodeando este agujero central hay un numero de otros agujeros que se llaman agujeros para precalentar. Las diferencias en el tipo o número de agujeros percalentados determina el tipo de gas combustible que se usará en la boquilla.

preheat temperature. The temperature of the base metal or substrate in the welding, brazing, soldering, thermal spraying, or thermal cutting area immediately before these operations are performed. In a multipass operation, it is also the temperature in the area immediately before the second and subsequent passes are started.
temperatura de precalentamiento. La temperatura del metal base o substrato en la soldadura, soldadura fuerte, soldadura blanda, rociado termal, o en la área de los cortes termal inmediatamente antes de que estas operaciones sean ejecutadas. En una operación multipasada, es también la temperatura en la área inmediatamente antes de empezar la segunda pasada y pasadas subsiguientes.

preheating. The application of heat to the base metal immediately before welding, brazing, soldering, thermal spraying, or cutting.
precalentamiento. La aplicación de calor al metal base inmediatamente antes de la soldadura, soldadura fuerte, soldadura blanda, rociado termal o cortes.

***prepurge.** In gas tungsten arc welding, the time during which gas flows through the torch to clear out any air in the cup or surrounding the weld zone. Prepurge time is set by the operator and is completed before the welding current is started.
prepurgar. En soldadura de arco de tungsteno con gas, el tiempo durante el cual el gas corre por la antorcha para quitar el aire en la boquilla o la zona de soldadura. El tiempo de prepurgar es determinado por el operador y es acabado antes de que la corriente de soldadura es empezada.

***primary combustion.** The first reaction in the chemical reaction resulting when a mixture of acetylene and oxygen is ignited. This reaction frees energy and forms carbon monoxide (CO) and free hydrogen.
combustión primaria. La primera reacción en una reacción química resulta cuando una mezcla de oxígeno y acetileno es encendida. Está reacción libra la energia y forma carbón monóxido (CO) e hidrógeno libre.

procedure qualification. The demonstration that welds made by a specific procedure can meet prescribed standards.
calificación de procedimiento. La demostración en que las soldaduras hechas por un procedimiento específico conformen con las normas prescribidas.

projection weld. A weld made by projection welding.
soldadura de proyección. Una soldadura hecha con soldadura de proyección.

protective atmosphere. A gas envelope surrounding the part to be brazed, welded, or thermal sprayed, with the gas composition controlled with respect to chemical composition, dew point, pressure, flow rate, etc. Examples are inert gases, combusted fuel gases, hydrogen, and vacuum.
atmósfera protectora. Una envoltura de gas que está alrededor de la parte que está para soldarse con soldadura fuerte, soldadura o rociada termal, con la composición del gas controlado con respecto a la química compuesta, punto de rocío, presión, cantidad de corriente, etc. Ejemplos son gas inerto, gases de combustión que ya están encendidos, hidrógeno, y vacuo.

***proximity sensor.** A device that senses that an object is only a short distance (e.g., a few inches or feet) away and/or measures how far away it is. Proximity sensors work on the principles of triangulation of reflected light, lapsed time for reflected sound, or intensity-induced eddy currents, magnetic fields, back pressure from air jets, and others.
sensor de proximidad. Un aparato que siente que un objeto está solamente a una corta distancia (e.g., unas pulgadas o pies) afuera, y/o mide que tan lejos está. Sensores de proximidad trabajan en los fundamentos de triangulación de luz reflejada, tiempo lapso del sonido reflejado, o en las corrientes de Fancault inducidas con intensidad, campos magnéticos, contrapresión trasera del chorro de aire, y otras.

puddle. See preferred term weld pool.
charco. Vea término preferido charco de soldadura.

pulse start delay time. The time interval from current initiation to the beginning of current pulsation, if pulsation is used. Refer to drawing for upslope time.
tiempo de dilación en empezar la pulsación. El tiempo del intervalo de donde se inicia la corriente al principio de la pulsación de la corriente, si es que se use pulsación. Refiérase al dibujo de tiempo del pendiente en ascenso.

***pulsed-arc metal transfer.** In gas metal arc welding, pulsing the current from a level below the transition current to a level above the transition current to achieve a controlled spray transfer at lower average currents; spray transfer occurs at the higher current level.
transferir el metal por arco pulsado. En la soldadura de arco metálico con gas, se pulsa la corriente de un nivel más alto de la corriente de transición para lograr un traslado de rocío controlado a una corriente media baja; el traslado del rocío ocurre al nivel más alto de la corriente.

***purged.** The process of opening first one cylinder valve and then the other to replace all air in the hoses with the appropriate gas prior to welding.
limpidor. El proceso de abrir primero una válvula de un cilindro y luego el otro para reemplazar todo el aire en las mangueras con un gas apropiado antes de empezar a soldar.

push angle. The travel angle when the electrode is pointing in the direction of weld progression. This angle can also be used to partially define the position of guns, torches, rods, and beams.
ángulo de empuje. El ángulo de avance cuando el electrodo apunta en la dirección en que la soldadura progresa. Este ángulo también puede ser usado para parcialmente definir la posición de pistolas, antorchas, varillas, y rayos.

push welding. A resistance welding process variation in which spot or projection welds are produced by manually applying force to one electrode.
soldadura de empuje (soldadura de resistencia). Una soldadura de botón o proyección hecha por soldadura de empuje.

Q

qualification. See preferred terms welder performance qualification and procedure qualification.
calificación. Vea términos preferidos calificación de ejecución del soldador y calificación de procedimiento.

***quality control.** A procedure of tests set up by shops to inspect weldments as they are produced to ensure that they meet the standards set up by the manufacturer.
control de calidad. Procedimiento de pruebas diseñadas por los talleres para inspeccionar las soldaduras a medidas que son producidas, con el propósito de asegurarse de que cumplan con los estándares fijados por el fabricante.

R

***radiographic inspection (RT).** See nondestructive testing.
inspección radiográfica (RT). Ver prueba no destructiva.

reactor (arc welding). A device used in arc welding circuits for the purpose of minimizing irregularities in the flow of welding current.
reactor (soldadura de arco). Un aparato usado en los circuitos de la soldadura de arco con el propósito de reducir a lo mínimo las irregularidades en la manera que corre la corriente de soldadura de arco.

reduced section tension test. A test in which a transverse section of the weld is located in the center of the reduced section of the specimen.
prueba de tensión de sección reducida. Una prueba en la cual la sección transversa de la soldadura está ubicada en el centro de la sección reducida de la probeta.

reducing atmosphere. A chemically active protective atmosphere, which at elevated temperature will reduce metal oxides to their metallic state. (Reducing atmosphere is a relative term, and such an atmosphere may be reducing to one oxide but not to another oxide.)
atmósfera de reducción. Una atmósfera protectiva activa, la cual a una temperatura elevada reduce los óxidos del metal a sus estados metalicos. (Atmósfera de reducción es un término relativo, y cierta atmósfera puede reducir a un óxido pero no al otro óxido.)

reducing flame. An oxyfuel gas flame with an excess of fuel gas.
llama de reducción. Una llama de gas oxicombustible con un exceso de gas combustible.

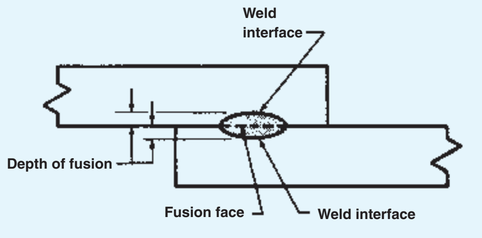
regulator. A device for controlling the delivery of gas at some substantially constant pressure.
regulador. Un aparato para controlar la expedición de gas a una presión substancialmente constante.

residual stress. Stress present in a joint member or material that is free of external forces or thermal gradients.
fuerza residual. Fuerza presente en un miembro de una junta o material que está libre de fuerzas externas o ambulantes termales.

resistance brazing (RB). A brazing process using heat from the resistance to electric current flow in a circuit that includes the assembly.
soldadura fuerte por resistencia (RB). Un proceso de soldadura fuerte que usa calor de la resistencia al correr de la corriente eléctrica en un circuito en las cuales las piezas de trabajo forman parte.

resistance soldering (RS). A soldering process that uses heat from the resistance to electric current flow in a circuit of which the workpieces are a part.
soldadura blanda por resistencia (RS). Un proceso de soldadura blanda que usa calor de la resistencia al correr de la corriente eléctrica en un circuito en las cuales las piezas de trabajo forman parte.

resistance spot welding (RSW). A resistance welding process that produces a weld at the faying surfaces of a joint by the heat obtained from resistance to the flow of welding current through the workpieces from electrodes that concentrate the welding current and pressure at the weld area.
soldadura de puntos por resistencia (RSW). Un proceso de soldar por resistencia que produce una soldadura en los empalmes de la superficie de una junta por el calor obtenido de la resistencia al correr la corriente a través de las piezas de trabajo de los electrodos que sirven para concentrar la corriente para soldar y la presión en la área de la soldadura.



Resistance spot or seam weld

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resistance welding (RW). A group of welding processes that produces coalescence of the faying surfaces with the heat obtained from resistance of the workpieces to the flow of the welding current of which the workpieces are a part and by the application of pressure.
soldadura por resistencia (RW). Un grupo de procesos para soldar que producen coalescencia de las superficies empalmadas con el calor obtenido de la resistencia de las piezas de trabajo al correr la corriente de soldadura en un circuito en las cuales las piezas de trabajo forman parte, y por la aplicación de presión.

resistance welding downslope time. The time during which the welding current is continuously decreasing.
tiempo del pendiente de descenso en soldadura de resistencia. El tiempo durante el cual la corriente está continuamente disminuyendo.

resistance welding electrode. The part of a resistance welding machine through which the welding current and, in most cases, force are applied directly to the workpiece. The electrode may be in the form of a rotating wheel, rotating roll, bar, cylinder, plate, clamp, chuck, or modification thereof.
electrodo para soldadura por resistencia. La parte de una máquina para soldar por resistencia por cual la corriente de soldar y, en muchos casos, la fuerza es aplicada directamente a la pieza de trabajo. El electrodo puede ser en la forma de una rueda que da vueltas, rollo rotativo, barra, cilindro, plato, empalme, calzo, o modificación de ello.

reverse polarity. The arrangement of direct-current arc welding leads with the work as the negative pole and the electrode as the positive pole of the welding arc. A synonym for direct-current electrode. Refer to drawing for direct-current electrode positive.
polaridad invertida. El arreglo de los cables para soldar con el arco con corriente directa con el cable de tierra como el polo negativo y el electrodo como polo positivo del arco para soldar. Un sinónimo para corriente directa electrodo. Refiérase al dibujo para corriente directa con el electrodo positivo.

***robot.** A reprogrammable, multifunctional manipulator designed to move material, parts, tools, or specialized devices through variable programmed motions for the performance of a variety of tasks.
robot. Un manipulador reprogramable, multifuncional diseñado para mover material, partes, herramienta, o aparatos especializados por medio de mociones programadas variables para la ejecución de una variedad de tareas.

***robot programming language.** A computer language especially designed for writing programs for controlling robots.
lenguaje para programación del robot. Un lenguaje para computadoras con un diseño especial para escribir programas para el control de los robots.

root. See preferred terms of root of joint and root of weld.
raíz. Vea las términos preferidos de raíz de junta y raíz de soldadura.

root bead. A weld bead extending into, or including part or all of, the joint root.
cordón de raíz. Un cordón de soldadura que se extiende adentro, o incluye parte o toda la junta de raíz.

root-bend test. A test in which the weld root is on the convex surface of a specified bend radius.
prueba de dobléz de raíz. Una prueba en la cual la raíz de la soldadura está en una superficie convexa de un radio especificado para el dobléz.

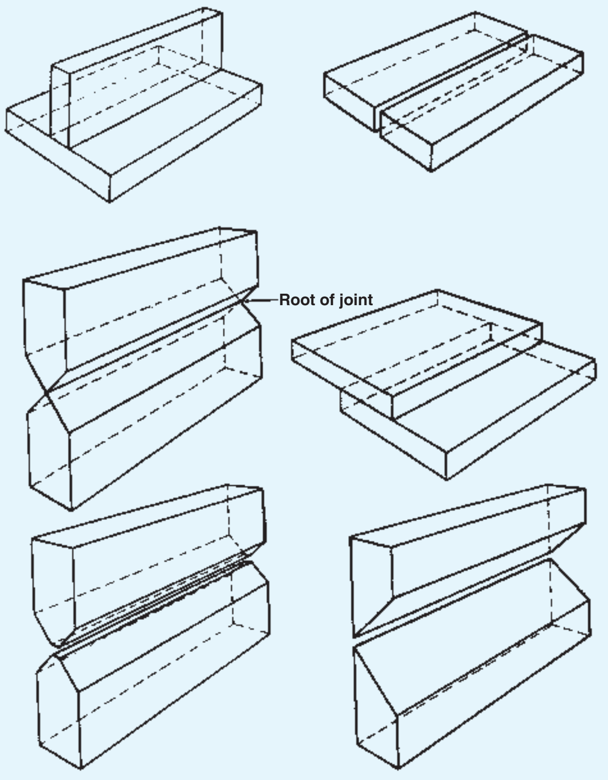
root crack. A crack in the weld or heat-affected zone occurring at the root of a weld.
grieta de raíz. Una grieta en la soldadura o en la zona afectada por el calor que ocurre en la raíz de la soldadura.

root edge. A root face of zero width. See also root face. Refer to drawing for groove face.
orilla de raíz. Una cara de raíz con una anchura de cero. Vea también cara de raíz. Refiérase al dibujo para cara de ranura.

root face. The portion of the groove face adjacent to the root of the joint. Refer to drawing for groove face.
cara de raíz. La porción de la cara de la ranura adyacente a la raíz de la junta. Refiérase al dibujo para cara de ranura.

root gap. See preferred term root opening.
rendija de raíz. Vea el término preferido abertura de ráiz.

root of joint. The portion of a joint to be welded where the members approach closest to each other. In a cross section, the root of the joint may be a point, a line, or an area.
raíz de junta. Saporción de una junta que está para soldarse donde los miembros se acercan muy cerca del uno al otro. En sección transversa, la raíz de una junta puede ser una punta, una línea, o una área.



Root of joint
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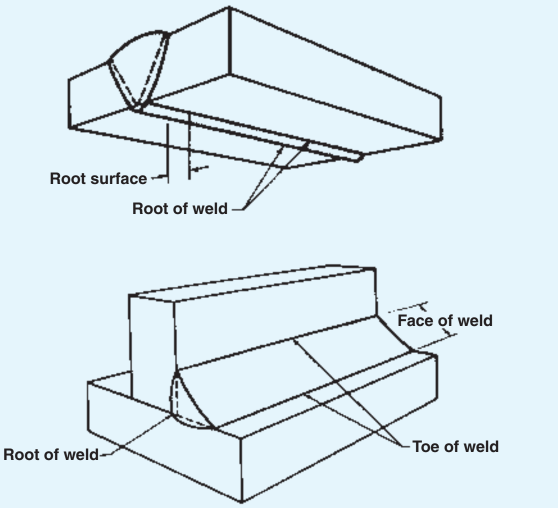
root of weld. The points, as shown in a cross section, at which the back of the weld intersects the base metal surfaces.
raíz de soldadura. Las puntas, como ensena la sección transversa, donde la parte de atrás cruza con la superficie del metal base.



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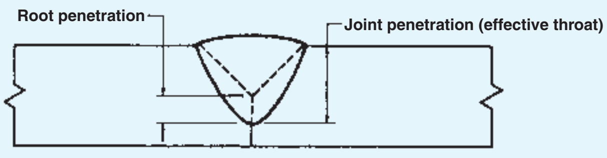
root opening. The separation between the members to be joined at the root of the joint. Refer to drawings for bevel.
abertura de raíz. La separación entre los miembros que están para unirse a la raíz de la junta. Refiérase al dibujo para bisel.

***root pass.** The first weld of a multipass weld. The root pass fuses the two pieces together and establishes the depth of weld metal penetration.
pasada de raíz. La primera soldadura de una soldadura de pasadas múltiples. La pasada de raíz funde las dos piezas juntas y establece la profundidad de la penetración del metal soldado.

root penetration. The distance the weld metal extends into the joint root.
penetración de raíz. La distancia que se extiende el metal de soldadura adentro de la junta de raíz.



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root radius. See preferred term groove radius.
radio de raíz. Vea el término preferido radio de ranura.

root reinforcement. Reinforcement of weld at the side other than that from which welding was done. Refer to drawing for face of weld.
refuerzo de raíz. Refuerzo de soldadura en el lado opuesto de donde se hizo la soldadura. Refiérase al dibujo para cara de la soldadura.

***root suck back.** The process that occurs when surface tension of the molten weld pool root surface is drawn inward causing the root surface to be concave.
succión de raíz. Proceso que ocurre cuando la tensión superficial de una raíz de soldadura derretida se invierte, causando que la superficie raíz tome forma cóncava.

root surface. The exposed surface of a weld on the side other than that from which welding was done. Refer to drawings for root of weld.
superficie de raíz. La superficie expuesta de una soldadura en el lado opuesto de donde se hizo la soldadura. Refiérase a los dibujos para raíz de soldadura.

runoff weld tab. Additional material that extends beyond the end of the joint, on which the weld is terminated.
solera de carrera final de soldadura. Material adicional que se extiende más allá de donde se acaba la junta, en la cual la soldadura es terminada.

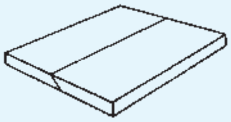
***rutile-based fluxes.** Acidic fluxes that produce smooth stable arcs and fast-freeze slags.
flujos por destello. Flujos acídicos que producen arcos parejos y estables y escorias de solidificación rápida.

S

Safety Data Sheet (SDS). The SDS includes information such as the properties of each chemical; the physical, health, and

environmental health hazards; protective measures; and safety precautions for handling, storing, and transporting the chemical.
La Ficha de Datos de Seguridad. El SDS incluye información como las propiedades de cada producto químico; la física, la salud y los riesgos de salud ambiental; medidas de protección; y medidas de seguridad para el manejo, almacenamiento y transporte de la sustancia química.

scarf joint. A form of a butt joint.
junta de echarpe. Una forma de junta a tope.



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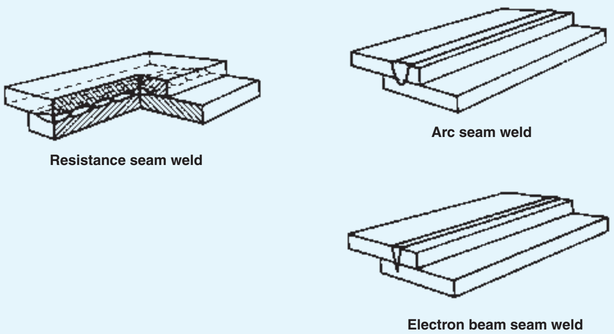
***scavenger.** Elements in the flux that pick up contaminants in the molten weld pool and float them to the surface where they become part of the slag.
limpiadores o (expulsadores). Elementos en el flujo que levantan los contaminantes en el charco de soldadura derretida y los flotan a la superficie donde se forman parte de la escoria.

seam weld. A continuous weld produced between overlapping members with coalescence initiating and occuring at faying surfaces proceeding from the outer surface of one member. The weld can consist of either a weld bead, multiple overlapping nuggets, or a single nugget formed by the simultaneous application of resistance heating and forging force along the weld joint.
soldadura de costura. Una soldadura continua hecha en medio o encima de los miembros traslapados, en la cual la coalescencia puede empezar y ocurrir en la superficie del empalme, o puede haber procedido de la superficie de un miembro. La soldadura continua puede consistir de un solo cordón de soldadura o una serie de puntos traslapados en las soldaduras.



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***secondary combustion.** In the combustion of acetylene and oxygen, the secondary reaction unites oxygen and the free hydrogen to form water vapor (H_2O) and liberate more heat. The carbon monoxide unites with more oxygen to form carbon dioxide (CO_2).
combustión secundaria. En la combustión de acetileno y oxígeno, la reacción secundaria une el oxígeno y el hidrógeno libre para formar vapor de agua (H_2O) y liberar más calor. El carbón monóxido se une con más oxígeno para formar carbón bióxido (CO_2).

***section line.** Lines on a drawing that show the surface that has been imaginarily cut away with a cutting plane line to show internal details.
línea de sección. Líneas de un dibujo que muestran la superficie que ha sido cortada imaginariamente con una línea de plano de corte para mostrar los detalles internos.

***section view.** A special view of an object that shows the internal components as if the object were cut apart.
vista de sección. Vista especial de un objeto que muestra los componentes internos como si el objeto hubiera sido cortado y separado.

***self-shielding.** As it relates to FCA welding, it refers to electrodes that contain enough fluxing agents inside the electrode to provide complete weld protection without the need to provide a shielding gas. See dual shield.
autoprotección. En relación a la soldadura FCA. Se refiere a los electrodos que contienen suficiente agentes fundentes en su interior como para proporcionar protección completa de la soldadura sin la necesidad de usar gas de protección. Ver protección doble.

semiautomatic arc welding. Arc welding with equipment that controls only the filler metal feed. The advance of the welding is manually controlled.
soldadura de arco semiautomático. La soldadura de arco con equipo que controla solamente la alimentación del metal de relleno. El avance de la soldadura es controlado manualmente.

***semiautomatic operation.** During the welding process, the filler metal is added automatically, and all other manipulation is performed manually by the operator.
operación semiautomática. Durante el proceso de la soldadura, el metal de relleno es añadido automáticamente, y todas las otras manipulaciones son ejecutadas manualmente por el operador.

***sensor.** A transducer whose input is a physical phenomenon and whose output is a quantitative measure of the physical phenomenon.
sensor. Un transducor cuya entrada es un fenómeno físico y cuya medida es una medida cuantitativa del fenómeno físico.

sequence time (automatic arc welding). See preferred term welding cycle.
tiempo de secuencia (soldadura de arco automático). Vea el término preferido ciclo de soldadura.

***shear strength.** As applied to a soldered or brazed joint, it is the ability of the joint to withstand a force applied parallel to the joint.
fuerza cizallada. Asi como es aplicada a una junta de soldadura fuerte o soldadura blanda, es la habilidad de la junta de resistir una fuerza aplicada al paralelo de la junta.

shielded metal arc cutting (SMAC). An arc cutting process employing a covered electrode.
cortes de arco métalico protegido (SMAC). Un proceso de cortar con arco que usa un electrodo cubierto.

shielded metal arc welding (SMAW). An arc welding process with an arc between a covered electrode and the weld pool. The process is used with shielding from the decomposition of the electrode covering, without the application of pressure, and with filler metal from the electrode.
soldadura de arco metálico protegido (SMAW). Un proceso de soldadura de arco con un arco en medio de un electrodo cubierto y el charco de soldadura. El proceso se usa con protección de descomposición del cubrimiento del electrodo sin la aplicación de presión, y con el metal de relleno del electrodo.

shielding gas. A gas used to produce a protective atmosphere.
gas protector. El gas protector se usa para prevenir o reducir la contaminación atmosférica.

short arc. A nonstandard term for short-circuiting transfer arc welding.
arco corto. Un término fuera de la norma para transferir por corto circuito (soldadura de arco).

short-circuiting arc welding. A nonstandard term for short-circuiting transfer (arc welding).
soldadura de arco con corto circuito. Un término fuera de la norma para transferir por corto circuito (soldadura de arco).

short-circuiting transfer (arc welding). Metal transfer in which molten metal from a consumable electrode is deposited during repeated short circuits.
transferir por corto circuito (soldadura de arco). Transferir metal el cual el metal derretido del electrodo consumible es depositado durante repetidos cortos circuitos.

shoulder. See preferred term root face.
hombro. Vea término preferido cara de raíz.

shrinkage void. A cavity-type discontinuity formed as a metal contracts during solidification.
vacío de encogimiento. Una discontinuidad tipo cavidad normalmente formada por encogimiento durante solidificación.

side-bend test. A test in which the side of a transverse section of the weld is on the convex surface of a specified bend radius.
prueba de dobléz de lado. Una prueba en la cual el lado de una sección transversa de la soldadura está en la superficie convexa de un radio de dobléz especificado.

***silver braze.** A brazing process using an alloyed brazing rod which contains some percentage of silver. Silver is used as an alloy to promote wetting and strength.
soldadura fuerte con plata. Proceso de soldadura fuerte que utiliza una vara de aleación que contiene un porcentaje de plata. La plata se usa como aleación para promover la exudación y la fortaleza.

silver soldering, silver alloy brazing. Nonpreferred terms used to denote brazing with a silver-base filler metal. See preferred term furnace brazing.
soldadura blanda con plata, soldadura fuerte con aleación de plata. Términos no preferidos que se usan para denotar soldadura fuerte con metal para rellenar con base de plata. Vea el término preferido soldadura fuerte en horno.

single bevel-groove weld. A type of groove weld. Refer to drawing for groove weld.
soldadura de ranura de un solo bisel. Tipo de soldadura de ranura. Refiérase al dibujo para soldadura de ranura.

single J-groove weld. A type of groove weld. Refer to drawing for groove weld.
soldadura de ranura de una sola J. Un tipo de soldadura de ranura. Refiérase al dibujo para soldadura de ranura.

single square-groove weld. A type of groove weld. Refer to drawing for groove weld.
soldadura de ranura de una sola escuadra. Un tipo de soldadura de ranura. Refiérase al dibujo de soldadura de ranura.

single U-groove weld. A type of groove weld. Refer to drawing for groove weld.
soldadura de ranura de una sola U. Un tipo de soldadura de ranura. Refiérase al dibujo para soldadura de ranura.

single V-groove weld. A type of groove weld. Refer to drawing for groove weld.
soldadura de ranura de una sola V. Un tipo de soldadura de ranura. Refiérase al dibujo de soldadura de ranura.

single-flare bevel-groove weld. A type of groove weld. Refer to drawing for groove weld.
soldadura de ranura de un solo bisel acampanado. Un tipo de soldadura de ranura. Refiérase al dibujo para soldadura de ranura.

single-flare V-groove weld. A type of groove weld. Refer to drawing for groove weld.
soldadura de ranura de una sola V acampanada. Un tipo de soldadura de ranura. Refiérase al dibujo para soldadura de ranura.

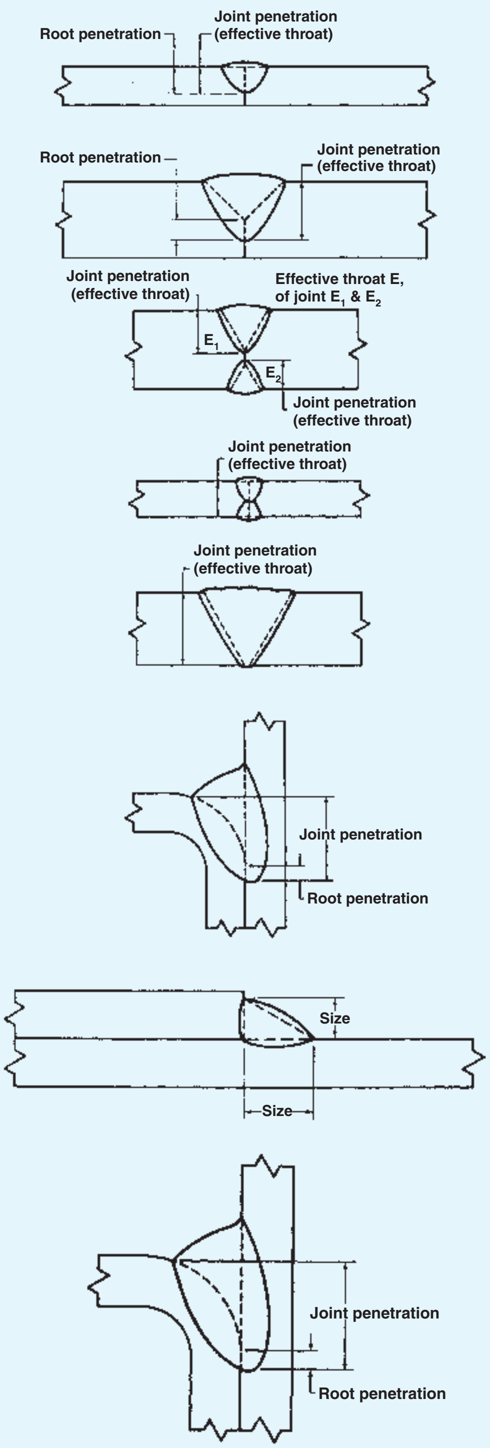
single-port nozzle. A constricting nozzle of the plasma arc torch that contains one orifice, located below and concentric with the electrode.
boquilla de una sola abertura. Es una boquilla constreñida de la antorcha de arco de plasma que contiene un orificio, situado debajo y concéntrico al electrodo.

size of weld.

- **groove weld.** The joint penetration (depth of bevel plus the root penetration when specified). The size of a groove weld and its effective throat are one and the same.
- **fillet weld.** For equal leg fillet welds, the leg lengths of the largest isosceles right triangle that can be inscribed within the fillet weld cross section. Refer to drawings for concavity and convexity. For unequal leg fillet welds, the leg lengths of the largest right triangle that can be inscribed within the fillet weld cross section.
  Note: When one member makes an angle with the other member greater than 105°, the leg length (size) is of less significance than the effective throat, which is the controlling factor for the strength of a weld.
- **flange weld.** The weld metal thickness measured at the root of the weld.

tamaño de la soldadura.

- **soldadura de ranura.** La penetración de la junta (profundidad del bisel más la penetración de la raíz cuando está especificada). El tamaño de la soldadura de ranura y la garganta efectiva son una y la misma.
- **soldadura filete.** Para soldaduras con piernas iguales de filete, lo largo de las piernas del triángulo recto con el isosceles más grande que puede ser inscrito dentro de la sección transversa de la soldadura de filete. Refiérase al dibujo para concavidad y convexidad. Para piernas de soldadura de filete desiguales, lo largo de las piernas del triángulo recto más grande que puede ser inscrito dentro de la sección transversa de la soldadura de filete.
  Nota: Cuando un miembro hace un ángulo con otro miembro más grande de 105 grados, lo largo de la pierna (tamaño) es de menor significado que la garganta efectiva, la cual es el factor de control para la fuerza de una soldadura.
- **soldadura de brida.** Lo grueso del metal de soldadura se mide a la raíz de la soldadura.



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slag. A nonmetallic product resulting from the mutual dissolution of flux and nonmetallic impurities in some welding and brazing processes.
escoria. Un producto que no es metálico resultando de una disolución mutual del flujo y las impuridades no metálicas en unos procesos de soldadura y soldadura fuerte.

slag inclusion. Nonmetallic solid material entrapped in weld metal or between weld metal and base metal.
inclusion de escoria. Material sólido no metálico atrapado en el metal de soldadura o entre el metal de soldadura y el metal base.

slag pan. A high-temperature container that holds the slag from a thermite weld until it cools.
bandeja para escoria. Un recipiente de alta temperatura que contiene la escoria de una soldadura con termita hasta que se enfría.

***slope.** For gas metal arc welding, the volt-ampere curve of the power supply indicates that there is a slight decrease in voltage as the amperage increases; the rate of voltage decrease in the slope.
pendiente. Para soldadura de arco de metal con gas, la curva voltio-amperio de la fuente de poder indica que si hay un ligero decremento en voltaje cuando los amerios aumentan; la proporción del voltaje decrementa en el pendiente.

slot weld. A weld made in an elongated hole in one member of a lap or tee joint joining that member to that portion of the surface of the other member that is exposed through the hole. The hole may be open at one end and may be partially or completely filled with weld metal. (A fillet-welded slot should not be construed as conforming to this definition.)
soldadura de ranura alargada. Una soldadura hecha en un agujero alargado en un miembro de una junta en solape o T uniendo ese miembro a esa porción de la superficie del otro miembro que está expuesto a través del agujero. El agujero puede ser abierto en una punta y puede ser parcialmente o completamente rellenado con metal de soldadura. (Una ranura alargada con soldadura de filete no debe de interpretarse como conforme a está definición.)

slugging. The act of adding a separate piece or pieces of material in a joint before or during welding that results in a welded joint not complying with design, drawing, or specification requirements.
usar trozos de metal. El acto de agregar una pieza o piezas separadas de material en una junta antes o durante la soldadura que resulta en una junta soldada que no cumple con diseño, dibujo, o las especificaciones requeridas.

solder. A filler metal used in soldering that has a liquidus not exceeding 840°F (450°C).
soldadura (material para soldar). Un metal de relleno usado para soldadura blanda que tiene un liquidus que no excede de 840°F (450°C).

soldering (S). A group joining process in which the workpiece(s) and solder are heated to the soldering temperature to form a solder joint.
soldadura blanda (S). Un grupo de procesos de soldadura que produce coalescencia de materiales calentándolos a una temperature de soldar y usando un metal para rellenar con un liquidus que no exceda de 840°F (450°C) y más abajo del solidus de los metales base. El metal para rellenar es distribuido en medio de las superficies empalmadas acopladas muy cerca de la junta por acción capilar.

soldering gun. An electrical heated soldering iron with a pistol grip.
pistola de soldar. Un fierro eléctrico para soldar con mango de pistola, rápido para calentarse, y tiene una punta relativamente pequeña.

solid state welding (SSW). A group of welding processes producing coalescence by the application of pressure without melting any of the joint components.

soldadura de estado sólido (SSW). Un grupo de procesos para soldar que produce coalescencia cuando se le aplica presión a una temperatura de soldadura más baja que las temperatures que se usan para derretir el metal base y el metal de relleno.

solidus. The highest temperature at which a metal is completely solid.
solidus. La temperatura más alta cuando un metal o una aleación está completamente sólido.

spatter. The metal particles expelled during welding and that do not form a part of the weld.
salpicadura. Las partículas de metal que se despidan cuando se está soldando y que no forman parte de la soldadura.

spatter loss. Metal lost due to spatter.
pérdida causa salpicadura. El metal perdido debido a la salpicadura.

spool. A filter metal package configuration in which the wire is wound on a cylinder (called a barrel), which is flanged at both ends. The flange contains a spindle hole centered inside the barrel.
carrete. Un paquete de metal tipo filtro consistiendo de una extensión continua de un electrodo enrollado en un cilindro (llamado el barril), el cual tiene una brida en los dos extremos. La brida se extiende debajo del diámetro de adentro del barril y contiene un agujero huso.

spot weld. A weld produced between or upon overlapping members with coalescence initating and occurring at faying surfaces or proceeding from the outer surface of one member. The weld typically has a round cross section in the plane of the faying surfaces. See also arc spot weld and resistance spot welding.
soldadura de puntos. Una soldadura hecha en medio o sobre miembros traslapados en la cual la coalescencia puede empezar y ocurrir en las superficies empalmadas o puede continuar en la superficie de un miembro. La sección transversa (plan de vista) es aproximadamente circular. Vea también soldadura de puntos por arco y soldadura de puntos por resistencia.

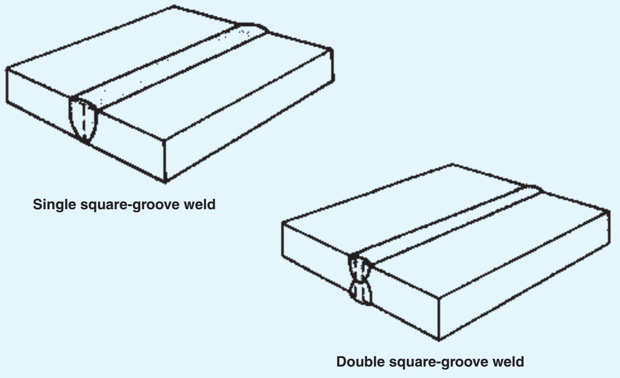
spray arc. A nonstandard term for spray transfer.
arco para rociar. Un término fuera de norma para traslado rociado.

spray transfer (arc welding). Metal transfer in which molten metal from a consumable electrode is propelled axially across the arc in small droplets.
traslado rociado (soldadura de arco). Transferir el metal el cual el metal derretido de un electrodo consumible es propelado axialmente a traves del arco en gotitas pequeñas.

***square butt joint.** A joint made when two flat pieces of metal face each other with no edge preparation. See also square groove weld.
junta escuadra de tope. Una junta hecha cuando dos piezas planas de metal se enfrentan una a la otra sin preparación de orilla. Vea también soldadura de ranura escuadra.

square butt weld. See butt joint.
junta escuadra de tope. Vea junta a tope.

square-groove weld. A type of groove weld.
soldadura de ranura escuadra. Un tipo de soldadura de ranura.



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stack cutting. Thermal cutting of stacked metal plates arranged so that all the plates are severed by a single cut.
corte de metal apilado. Un corte termal de hojas de metal apilados arregladas para que todas las hojas sean cortadas por un solo corte.

staggered intermittent welds. Intermittent welds on both sides of a joint in which the weld increments on one side are alternated with respect to those on the other side.
soldadura intermitente de cadena. Soldaduras intermitentes en los dos lados de una junta en cual los incrementos de soldadura son alternados de un lado con respecto a los del otro lado.

***stainless steels.** Alloys of steel containing enough chromium so that they do not stain, corrode, or rust easily.
acero inoxidable. Aleación de acero que contiene suficiente cantidad de cromo como para evitar que ésta se manche, corroa, o herrumbre fácilmente.

standoff distance. The distance between a nozzle and the workpiece.
distancia de alejamiento. La distancia entre la boquilla y la pieza de trabajo.

starting weld tab. Additional material that extends beyond the beginning of the joint, on which the weld is started.
solera para empezar a soldar. Material adicional que se extiende más allá del principio de la junta, en donde la soldadura es empezada.

***steel.** An alloy consisting primarily of iron and carbon. The carbon content may be as high as 2.2% but is usually less than 1.5%.
acero. Una aleación que consiste primeramente de hierro y carbón. El contenido del carbón puede ser tan alto como 2.2% pero es regularmente menos de 1.5%.

stick electrode. A nonstandard term for a covered electrode.
electrodo de varilla. Un término fuera de norma por electrodo cubierto.

stickout. See preferred term electrode extension.
sobresalga. Vea término preferido extensión del electrodo.

straight polarity. The arrangement of direct-current arc welding leads in which the work is the positive pole and the electrode is the negative pole of the welding arc. A synonym for direct-current electrode negative. Refer to drawing for direct-current electrode negative.
polaridad directa. El arreglo de los cables de soldadura de arco con corriente directa donde el cable de la tierra es el polo

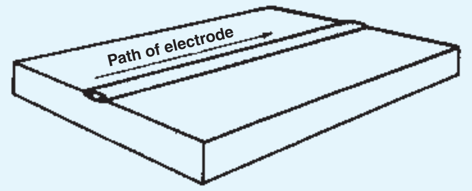
positivo y el porta electrodo es el polo negativo del arco de soldadura. Un sinónimo para corriente directa con electrodo negativo. Refiérase al dibujo para corriente directa con electrodo negativo.

stranded electrode. A composite filler metal electrode consisting of stranded wires that may mechanically enclose materials to improve properties, stabilize the arc, or provide shielding.
electrodo cable. Electrodo de metal para rellenar compuesto que consiste de cable de alambres que pueden encerrar materiales mecánicamente para mejorar propiedades, estabilizar el arco, o proveer protección.

***stress point.** Any point in a weld where incomplete fusion of the weld on one or both sides of the root gives rise to stress, which can result in premature cracking or failure of the weld at a load well under the expected strength of the weld.
punto de tensión. Cualquier punto en una soldadura donde la fusión incompleta en la soldadura en uno o en los dos lados de la raíz le aumenta la tensión, la cual puede resultar en una grieta o falta prematura en la soldadura con una carga mucho menos que la fuerza de la soldadura que se esperaba.

stress relief heat treatment. Uniform heating of a structure or a portion thereof to a sufficient temperature to relieve the major portion of the residual stresses, followed by uniform cooling.
tratamiento de calor para relevar la tensión. Calentamiento uniforme de una estructura o una porción a una temperatura suficiente para relevar la mayor porción de las tensiones restantes, seguido por enfriamiento uniforme.

stringer bead. A type of weld bead made without appreciable weaving motion. See also weave bead.
cordón encordador. Un tipo de cordón de soldadura sin movimiento del tejido apreciable. Vea también cordón tejido.



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stud arc welding (SW). An arc welding process that uses an arc between a metal stud, or similar part, and the other workpiece. The process is used with or without shielding gas or flux, with or without partial shielding from a ceramic ferrule surrounding the stud, with the application of pressure after the faying surfaces are sufficiently heated, and without filler metal.
esparrago (tachón) para soldadura de arco (SW). Un proceso de soldadura de arco que usa un arco entre un esparrago (tachón) de metal, o parte similar, y la otra pieza de trabajo. El proceso es usado con o sin flujo o protección de gas, con o sin protección parcial del casquillo cerámico que rodea el esparrago (tachón), con la aplicación de presión después que las superficies empalmadas tengan suficiente calor, y sin metal de relleno.

stud welding (SW). A general term for the joining of a metal stud or similar part to a workpiece. Welding may be accomplished by arc, resistance, friction, or other suitable process with or without external gas shielding.
soldadura de esparrago (tachón) (SW). Un término general para la unión de esparragos (tachones) o parte similar a una pieza de trabajo. La soldadura se puede efectuar por arco, resistencia, fricción, u otro proceso conveniente con o sin gas externo para protección.

submerged arc welding (SAW). An arc welding process using an arc or arcs between a bare metal electrode or electrodes and the weld pool. The arc and molten metal are shielded by a blanket of granular flux on the workpieces. The process is used without pressure and with filler metal from the electrode and sometimes from a supplemental source (welding rod, flux, or metal granules).
soldadura por arco sumergido (SAW). Un proceso de soldar con arco que usa un arco o arcos entre un electrodo de metal liso o electrodos y el charco de la soldadura. El arco y el metal derretido son protegidos por una capa de flujo granular sobre la pieza de trabajo. El proceso es usado sin presión y con metal para rellenar del electrodo y a veces de una fuente suplementaria (varilla para soldar, flujo, o gránulos de metal).

substrate. Any base material to which a thermal sprayed coating or surfacing weld is applied.
substrato. Cualquier material base al cual se le aplica una capa termal o una soldadura de superficie.

suck back. See preferred term concave root surface.
succión del cordón de raíz. Vea el término preferido superficie raíz concavo.

surface preparation. The operations necessary to produce a desired or specified surface condition.
preparación de la superficie. Las operaciones necesarias para producir una deseada o una especificada condición de la superficie.

surfacing. The application by welding, brazing, or thermal spraying of a layer of material to a surface to obtain desired properties or dimensions, as opposed to making a joint. See also buttering, cladding, coating, and hardfacing.
recubrimiento superficial. La aplicación a la soldadura, a la soldadura fuerte o rociado termal de una capa de material a la superficie para obtener las deseadas propiedades o dimensiones, contrario a la hechura de una junta. Vea también recubrimiento antes de terminar una soldadura, capa de revestimiento, revestimiento, y endurecimiento de caras.

***synergic system.** Pulsed-arc metal transfer system in which the power supply and wire-feed settings are made by adjusting a single knob.
sistema sinérgico. Sistema de transferir metal por arco pulsado en cual la fuente de poder y los ajustes del alimentador de alambre son hechos por el ajuste de un botón solamente.

T

tab. See runoff weld tab, starting weld tab, and weld tab.
solera. Vea solera de carrera final de soldadura, solera para empezar a soldar, y solera para soldar.

tack weld. A weld made to hold parts of a weldment in proper alignment until the final welds are made.
soldadura de puntos aislados. Una soldadura hecha para detener las partes en su propio alineamiento hasta que se hagan las soldaduras finales.

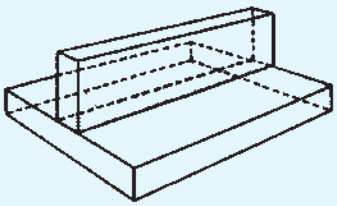
***tactile sensor.** A transducer that is sensitive to touch.
sensor táctil. Un transducor que es sensitivo al tocar.

taps. Connections to a transformer winding that are used to vary the transformer turns ratio, thereby controlling welding voltage and current.
grifo. Conexiones al arrollamiento de un transformador que se usan para variar la proporción de vueltas del transformador, asi se puede controlar la corriente y el voltaje para soldar.

***teach.** To program a manipulator arm by guiding it through a series of points or in a motion pattern that is recorded for subsequent automatic action by the manipulator.
enseñar. Para programar un manipulador de brazo guiándolo por una serie de puntos o en una muestra de movimiento que está registrada para acción automática subsiguiente por el manipulador.

***teaching interface.** The mechanisms or devices by which a human operator teaches a machine.
enseñanza de interfaze. Los mecanismos o aparatos por los cuales un operador humano enseña a la máquina.

tee joint. A joint between two members located approximately at right angles to each other in the form of a *T*.
junta en T. Una junta en medio de dos miembros que están localizados aproximadamente a ángulos rectos de uno al otro en la forma de *T*.



T-joint

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***tempering.** Reheating hardened metal before it cools to room temperature to make it tough, not brittle.
templar. Recalentando un metal endurecido antes de que se enfrie a la temperatura del ambiente para hacerlo duro, no frágil.

***tensile strength.** As applied to a brazed or soldered joint, the ability of the joint to withstand being pulled apart.
resistencia a la tensión. Como es aplicada a una junta de soldadura fuerte o soldadura blanda, la capacidad de una junta que resista ser estirada hasta que se rompa en dos pedazos.

tension test. A test in which a specimen is loaded in tension until failure occurs. See also reduced section tension test.
prueba de tensión. Una prueba en la cual la probeta está cargada de tensión hasta que ocurra el fracaso. Vea también prueba de tensión de sección reducida.

thermal cutting (TC). A group of cutting processes severing or removing metal by localized melting, burning, or vaporizing of the workpiece. See also arc cutting, electron beam cutting, laser beam cutting, and oxygen cutting.
corte termal (TC). Un grupo de procesos para cortar que desúne o quita el metal para derretir o quemar o vaporizar localmente las piezas de trabajo. Vea también corte con arco, cortes rayo de electron, corte de rayo laser, y cortes de oxígeno.

thermal spraying (THSP). A group of processes in which finely divided metallic or nonmetallic surfacing materials are deposited in a molten or semimolten condition on a substrate to form a thermal spray deposit. The surfacing material may be in the form of powder, rod, cord, or wire.
rociado termal (THSP). Un grupo de procesos el cual los materiales metálicos o no metálicos de superficie que son depositados en una condición derretida o semiderretida sobre el substrato para formar un depósito de rociado termal. El material de superficie puede ser en forma de polvo, varilla, cordón, o alambre.

thermal stresses. Stresses in a material or assembly resulting from nonuniform temperature distribution or differential thermal expansion.
tensión termal. Tensiones en el metal resultando cuando la distribución de la temperatura no está uniforme.

thermite welding (TW). A welding process producing coalescence of metals by heating them with superheated liquid metal from a chemical reaction between a metal oxide and aluminum, with or without the application of pressure.
soldadura termita (TW). Un proceso de soldadura que produce coalescencia del metal calentándolos con un metal supercalentado líquido da una reacción química entre un metal óxido y el aluminio, con o sin la aplicación de presión. El metal de relleno, cuando es usado, es obtenido del metal líquido.

throat area, *resistance welding*. The region bounded by the physical components of the secondary circuit in a welding machine.
área de garganta, *soldadura por resistencia*. La área limitada por las partes físicas del circuito secundario en un punto de resistencia, costura, o una máquina de soldar de proyección. Se usa para determinar las dimensiones de una parte que puede ser soldada y determinar, en parte, la impedancia secundaria del equipo.

throat depth, *resistance welding*. The distance from the centerline of the electrodes or platens to the nearest point of interference for flat sheets.

> **actual throat.** The shortest distance from the root of weld to its face. Refer to drawing for convexity.
> **effective throat.** The minimum distance minus any reinforcement from the root of weld to its face. Refer to drawing for convexity.
> **theoretical throat.** The distance from the beginning of the root of the joint perpendicular to the hypotenuse of the largest right triangle that can be inscribed within the fillet weld cross section. This dimension is based on the assumption that the root opening is equal to zero. Refer to drawing for convexity.

profundidad de garganta, *soldadura por resistencia*. En una punta de resistencia, costura, o máquina de soldar de proyección, la distancia de la línea del centro del electrodo o platinas al punto más cercano de interferencia para las hojas planas.

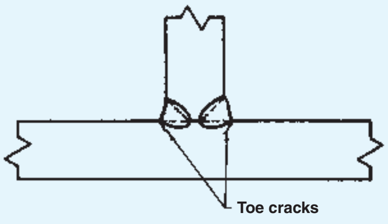
> **garganta actual.** La distancia más corta de la raíz de una soldadura a su cara. Refiérase al dibujo para convexidad.
> **garganta efectiva.** La distancia mínima menos cualquier refuerzo de la raíz de la soldadura a su cara. Refiérase al dibujo para convexidad.
> **garganta teórica.** La distancia de donde empieza la raíz de la junta perpendicular a la hipotenusa del triángulo recto más grande que puede ser inscrito adentro de la sección transversa

de una soldadura de filete. Esta dimensión está basada en la proposición que la abertura de la raíz es igual a cero. Refiérase al dibujo para **convexidad.**

TIG welding. A nonstandard term when used for gas tungsten arc welding.
soldadura TIG. Un término fuera de norma cuando es usado por soldadura de arco de tungsteno con gas.

***titanium.** This silver colored metal has a high strength to weight ratio which is why it is used extensively in the aerospace industry.
titanio. Metal de color plateado con proporción dureza-peso alta y por lo cual se usa extensamente en la industria aeroespacial.

toe crack. A crack in the base metal occurring at the toe of a weld.
grieta de pie. Una grieta en el metal base que ocurre al pie de la soldadura.



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toe of weld. The junction between the face of a weld and the base metal. Refer to drawing for **face of weld.**
pie de la soldadura. La unión entre la cara de la soldadura y el metal base. Refiérase al dibujo para **cara de la soldadura.**

tolerance. The allowable deviation in accuracy or precision between the measurement specified and the part as laid out or produced.
tolerancias. Desviación permitida en la precisión entre la medida especificada y la pieza instalada o producida.

torch. See preferred terms **cutting torch** and **welding torch.**
antorcha. Vea el término preferido **antorcha para cortar** y **antorcha para soldar.**

***torch angle.** The angle between the centerline of the torch and the work surface; the ideal torch angle is 45°. The torch angle affects the percentage of heat input into the metal, thus affecting the speed of melting and the size of the molten weld pool.
ángulo de antorcha. El ángulo en medio de la línea del centro de la antorcha y la superficie del trabajo; el ángulo ideal de la antorcha es 45°. El ángulo de la antorcha afecta el por ciento de calor que entra dentro del metal, asi afectando la rapidez de derretimiento y el tamaño del charco del metal derretido de la soldadura.

torch brazing (TB). A brazing process that uses heat from a fuel-gas flame.
soldadura fuerte con antorcha (TB). Un proceso de soldadura fuerte que usa calor de una llama de gas combustible.

***torch manipulation.** The movement of the torch by the operator to control the weld bead characteristics.
manipulacion de la antorcha. El movimiento de la antorcha por el operador para el control de las características del cordón de la soldadura.

torch soldering (TS). A soldering process that uses heat from a fuel-gas flame.
soldadura blanda con antorcha (TS). Un proceso de soldadura blanda que usa calor de una llama de gas combustible.

***trailing edge.** See **electrode angle.**
borde del flujo. Ver **ángulo del electrodo.**

transducer. A device that transforms one form of energy into another.
transducor. Un aparato que convierte una forma de energía a otra.

transferred arc. A plasma arc established between the electrode of the plasma arc torch and the workpiece.
arco transferido. Un arco de plasma establecido entre el electrodo de la antorcha de arco de plasma y la pieza de trabajo.

***transition current.** In gas metal arc welding, current above a critical level to permit spray transfer; the rate at which drops are transferred changes in relationship to the current. Transition current depends upon the alloy bearing welded and is proportional to the wire diameter.
corriente de transición. En soldadura de arco y metal con gas, corriente arriba de un nivel crítico para permitir el traslado del rociado; la proporción en la cual las gotas son transferidas cambia en relación a la corriente. La corriente de transición depende del aleado que se está soldando y es proporcional al diámetro del alambre.

transverse face bend. See **face bend.**
doblez de cara transversal. Vea **doblez de cara.**

transverse root bend. See **root bend.**
cordón de raíz transversal. Vea **cordón de raíz.**

travel angle. The angle less than 90° between the electrode axis and a line perpendicular to the weld axis, in a plane determined by the electrode axis and the weld axis. The angle can also be used to partially define the position of guns, torches, rods, and beams. See also **drag angle** and **push angle.** Refer to drawing for **backhand welding.**
ángulo de avance. El ángulo menos de 90° entre el eje del electrodo y una línea perpendicular al eje de la soldadura, en un plano determinado por el eje del electrodo y el eje de la soldadura. El ángulo también puede ser usado para parcialmente definir la posición de las pistolas, antorchas, varillas, y rayos. Vea también **ángulo del tiro** y **ángulo de empuje.** Refiérase al dibujo para **soldadura en revés.**

travel angle (pipe). The angle less than 90° between the electrode axis and a line perpendicular to the weld axis at its point of intersection with the extension of the electrode axis, in a plane determined by the electrode axis and a line tangent to the pipe surface of the same point. This angle can also be used to partially define the position of guns, torches, rods, and beams. Refer to drawing for **backhand welding.**
ángulo de avance (tubo). El ángulo menos de 90° entre el eje del electrodo y la línea perpendicular al eje a su punto de intersección con la extensión del eje del electrodo, en un plano determinado por el eje del electrodo y una línea tangente a la superficie del tubo del mismo punto. Este ángulo también puede ser usado para parcialmente definir la posición de las pistolas, varillas, y rayos. Refiérase al dibujo para **soldadura en revés.**

***tungsten.** This steel-gray metal has a melting temperature of 6170°F (3410°C) and it freely emits electrons which makes it ideal for the nonconsumable electrodes for PAC, PAW, and GTAW processes.
tungsteno. Metal de color gris que posee una temperatura de fusión de 6170°F (3410°C) y que emite libremente electrodos, lo

cual lo hace ideal para los electrodos no consumibles de los procesos PAC, PAW, y GTAW.

tungsten electrode. A nonfiller metal electrode used in arc welding, arc cutting, and plasma spraying, made principally of tungsten.
electrodo de tungsteno. Un electrodo de metal que no se rellena que se usa para soldadura de arco, cortes por arco, rociado por plasma, y hecho principalmente de tungsteno.

***type A fire extinguisher.** An extinguisher used for combustible solids, such as paper, wood, and cloth. Identifying symbol is a green triangle enclosing the letter *A*.
extinguidor para incendios tipo A. Un extinguidor que se usa para combustibles sólidos como papel, madera, y tela. El símbolo de identificación es un triángulo verde con la letra *A* adentro.

***type B fire extinguisher.** An extinguisher used for combustible liquids, such as oil and gas. Identifying symbol is a red square enclosing the letter *B*.
extinguidor para incendios tipo B. Un extinguidor que se usa para liquidos combustibles, como aceite y gas. El símbolo de identificación es un cuadro rojo con la letra *B* adentro.

***type C fire extinguisher.** An extinguisher used for electrical fires. Identifying symbol is a blue circle enclosing the letter *C*.
extinguidor para incendios tipo C. Un extinguidor que se usa para incendios eléctricos. El símbolo de identificación es un círculo azul con la letra *C* adentro.

***type D fire extinguisher.** An extinguisher used on fires involving combustible metals, such as zinc, magnesium, and titanium. Identifying symbol is a yellow star enclosing the letter *D*.
extinguidor para incendios tipo D. Un extinguidor que se usa para incendios de metales combustibles, como zinc, magnesio, y titanio. El símbolo de identificación es una estrella amarilla con una letra *D* adentro.

U

U-groove weld. A type of groove weld.
soldadura de ranura en U. Un tipo de soldadura de ranura.

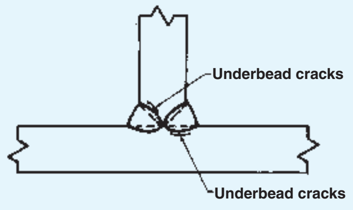
ultrasonic coupler (ultrasonic soldering and ultrasonic welding). Elements through which ultrasonic vibration is transmitted from the transducer to the tip.
acoplador ultrasónico (soldadura blanda ultrasónica y soldadura ultrasónica). Los elementos por los cuales la vibración ultrasónica es transmitida del transducor a la punta.

***ultrasonic inspection (UT).** See nondestructive testing.
inspección ultrasónica (UT). Ver prueba no destructiva.

ultrasonic welding (USW). A solid state welding process that produces a weld by the local application of high-frequency vibratory energy as the workpieces are held together under pressure.
soldadura ultrasónica. Un proceso de soldadura de estado sólido que produce una soldadura por la aplicación local de energía vibratoria de alta frecuencia asi cuando las piezas de trabajo están agarradas juntas bajo presión.

***ultraviolet light.** A very short wavelength light that is above the visible light range.
luz ultravioleta. Luz de longitud de onda muy corta que se encuentra por encima del espectro de la luz visible.

underbead crack. A crack in the heat-affected zone, generally not extending to the surface of the base metal.
grieta entre o bajo cordones. Una grieta en la zona afectada por el calor, generalmente no se extiende a la superficie del metal base.



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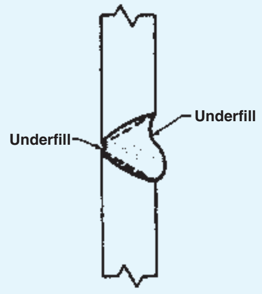
undercut. A groove melted into the base metal adjacent to the toe or root of a weld and left unfilled by weld metal. Refer to drawing for overlap.
socavación. Una ranura dentro del metal base adyacente al pie o raíz de la soldadura y se deja sin rellenar con el metal de soldadura. Refiérase al dibujo para traslapo.

underfill. A depression on the face of the weld or root surface extending below the surface of the adjacent base metal.
faltante de material. Una depresión en la cara de la soldadura o la superficie de la raíz extendiéndose más abajo de la superficie del adyacente metal base.



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uphill. Welding with an upward progression.
soldando hacia arriba. Solando con progresión hacia arriba.

***upper arm** (robot). The portion of a jointed arm that is connected to the shoulder.
brazo de arriba (robot). La porción que úne al brazo que conecta con el hombro.

upset. Bulk deformation of a workpiece(s) resulting from the application of pressure with or without added heat, expressed in terms of increase in transverse section area, reduction in length, reduction in thickness, or reduction of the cross wire weld stack height.
recalada. Deformación en bulto resultado de la aplicación de presión en la soldadura. El recalado puede ser medido como un aumento en porciento en una área interfacial, una reducción en lo largo, o un porciento de reducción en lo grueso para juntas de solape.

upset welding (UW). A resistance welding process producing a weld over the entire area of faying surfaces or progressively along a butt joint.
soldadura recalada (UW). Un proceso de soldadura por resistencia que produce coalescencia sobre toda la área de superficie empalmada o progresivamente sobre una junta a tope con el calor obtenido de la resistencia del flujo de la corriente de la

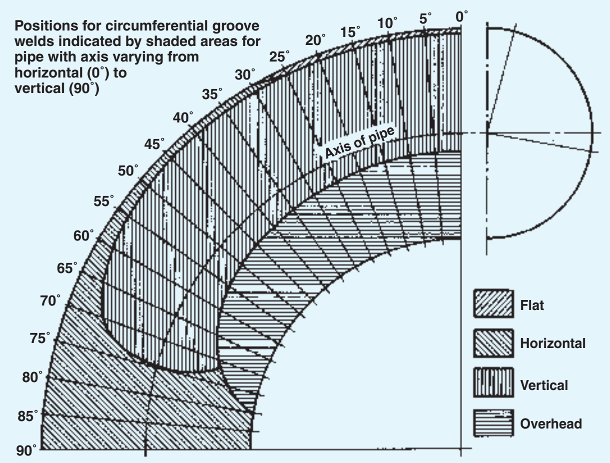
soldadura por la área donde esas superficies están en contacto. Presión es usada para completar la soldadura.

upslope time (automatic arc welding). The time during which the current changes continuously from initial current valve to the welding value.
tiempo del pendiente en ascenso (soldadura automática de arco). El tiempo durante el cual la corriente cambia continuamente el valor de la corriente inicial al valor de la soldadura.

V

***vector lines.** Lines the computer draws between two points. These lines always stay crisp and sharp even when the drawing is zoomed in (magnified) hundreds of times.
líneas vectoriales. Líneas que la computadora traza entre dos puntos. Estas líneas siempre se mantienen visibles y nítidas incluso cuando se aumenta (magnifica) el tamaño del dibujo cientos de veces.

vertical position. The position of welding in which the axis of the weld is approximately vertical.
posición vertical. La posición de la soldadura en la cual el eje para soldarse es aproximadamente vertical.



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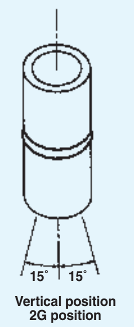
vertical position (pipe welding). The position of a pipe joint in which welding is performed in the horizontal position and the pipe may or may not be rotated.
posición vertical (soldadura de tubo). La posición de una junta de tubo en la cual la soldadura se hace en la posición horizontal y el tubo puede o no dar vueltas.



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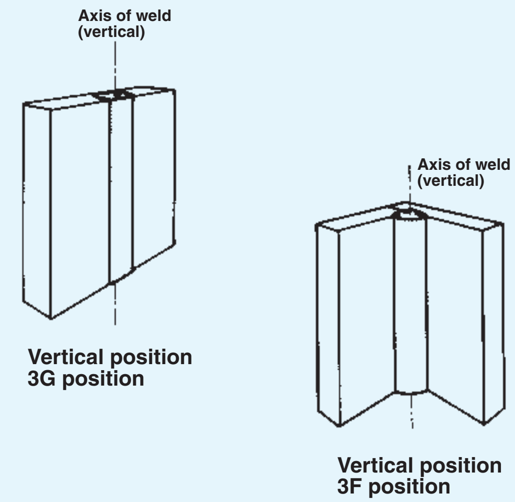
V-groove weld. A type of groove weld.
soldadura de ranura V. Un tipo de soldadura de ranura.

***visible light.** The light range that we see.
luz visible. El espectro de luz que podemos ver.



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voltage range. The lower and upper limits of welding power, in volts, that can be produced by a welding machine or used with an electrode or by a process.
rango de voltaje. Los límites máximos y mínimos de poder de soldadura (en voltios) que puede tener una máquina para soldar o que pueden usarse con un electrodo o a través de un proceso.

voltage regulator. An automatic electrical control device for maintaining a constant voltage supply to the primary of a welding transformer.
regulador de voltaje. Un aparato de control eléctrico automático para mantener y proporcionar un voltaje constante a la primaria de un transformador de una soldadura.

W

***wagon tracks.** A pattern of trapped slag inclusions in the weld that show up as discontinuities in X-rays of the weld.
huellas de carreta. Una muestra de inclusiones de escoria atrapadas en la soldadura que enseña que hay discontinuidades en los rayos-x de la soldadura.

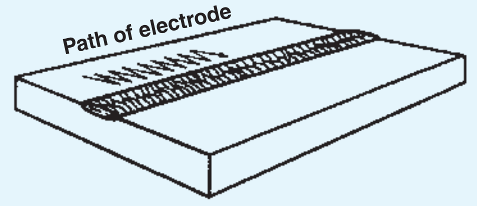
***water-arc plasma cutting (PAC).** In this process, nitrogen is used as the plasma gas. The plasma is created at a high temperature in an arc between the electrode and the orifice. A tap water spray applied to the plasma causes it to constrict and accelerate. This column causes the cutting action and melts a very narrow kerf in the material.
cortes de arco-agua plasma (PAC). En este proceso, nitrogeno es usado como el gas de plasma. La plasma es creada a una temperatura alta en un arco en medio del electrodo y la orifice. La aplicación de agua del grifo a la plasma la hace que se constriñe y acelera. Está columna causa la acción de cortar y derritir un corte que es muy estrecho en el material.

***water jet cutting.** A process using extremely high pressure water to cut through material.
corte con chorro de agua. Proceso que usa agua a presión extremadamente alta para cortar un material.

***wattage.** A measurement of the amount of power in the arc; the wattage of the arc controls the width and depth of the weld bead.
número de vatios. Una medida de la cantidad de poder en el arco; el número de vatios del arco controla lo ancho y hondo del cordón de la soldadura.

wax pattern (thermit welding). Wax molded around the workpieces to the form desired for the completed weld.
soldadura termita (molde de cera). Un molde de cera alrededor de las piezas de trabajo a la forma deseada para la soldadura terminada.

weave bead. A type of weld bead made with transverse oscillation.
cordón tejido. Un tipo de cordón de soldadura hecha con oscilación transversa.



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***weave pattern.** The movement of the welding electrode as the weld progresses; common weave patterns include circular, square, zigzag, stepped, C, J, T, and figure 8.
muestra de tejido. El movimiento del electrodo para soldar a como progresa la soldadura; las muestras de tejidos comunes incluyen circular, de cuadro, zigzag, de pasos, C, J, T, y la figura 8.

weld. A localized coalescence of metals or nonmetals produced either by heating the materials to suitable temperatures, with or without the application of pressure, or by the application of pressure alone and with or without the use of the filler material.
soldar. Una coalescencia localizada de metales o metaloides producida al calentar los materiales a una temperatura adecuada, con o sin la aplicación de presión, o por la aplicación de presión solamente y con o sin el uso del material de relleno.

weld axis. A line through the length of the weld, perpendicular to and at the geometric center of its cross section.
eje de la soldadura. Una línea a través de lo largo de la soldadura, perpendicular a y al centro geométrico de su sección transversa.

weld bead. A weld resulting from a single welding pass. See also stringer bead and weave bead.
cordón de soldadura. Una soldadura resultante de una soldadura de una sola pasada. Vea también cordón encordador y cordón tejido.

weld brazing. Brazing using heat from a welding process such that the preplaced brazing filler metal is melted to form a braze augmenting the weld by increasing joint strength, or creating a seal between spot or intermittent welds.
soldadura y soldadura fuerte. Un método de unir que combina soldadura de resistencia con soldadura fuerte.

weld crack. A crack located in the weld metal or heat-affected zone.
grieta en la soldadura. Una grieta en el metal de soldadura.

weld face. The exposed surface of a weld on the side from which welding was done.
cara de la soldadura. La superficie expuesta de una soldadura en el lado de donde se hizo la soldadura.

weld gauge. A device designed for measuring the shape and size of welds.
instrumento para medir la soldadura. Un aparato diseñado para comprobar la forma y tamaño de las soldaduras.

weld groove. A channel in the surface of a workpiece or an opening between two joint members that provides space to contain a weld.
soldadura de ranura. Un canal en la superficie de una pieza de trabajo o una abertura entre dos miembros de junta que provee espacio para contener una soldadura.

weld interface. The interface between weld metal and base metal in a fusion weld, between base metals in a solid state weld without filler metal, or between filler metal and base metal in a solid state weld with filler metal. Refer to drawing for depth of fusion.
interfaze de la soldadura. La interfase entre el metal de soldadura y el metal base en una soldadura de fusión, entre metales de base en una soldadura de estado sólido sin metal para rellenar, o entre metal de rellenar y metal base en una soldadura de estado sólido con metal para rellenar. Refiérase al dibujo grueso de fusión.

weld length. See effective length of weld.
largura de la soldadura. Vea distancia efectiva de soldadura.

weld metal. The portion of a fusion weld that has been completely melted during welding.
metal de soldadura. La porción de una soldadura de fusión que se ha derretido completamente durante la soldadura.

weld metal area. The area of the weld metal as measured on the cross section of a weld. Refer to drawing for heat-affected zone.
área de metal de soldadura. La área del metal de la soldadura la cual fue medida en la sección transversa de la soldadura. Refiérase al dibujo para zona afectada por el calor.

weld pass. A single progression of welding along a joint. The result of a pass is a weld bead or layer.
pasada de soldadura. Una progresión singular de la soldadura a lo largo de una junta. El resultado de una pasada es un cordón o una capa.

weld pass sequence. The order in which the weld passes are made. See also longitudinal sequence and cross-sectional sequence.
secuencia de pasadas de soldadura. La orden en que las pasadas de soldadura se hacen. Vea también secuencia longitudinal y secuencia del corte transversal.

weld penetration. A nonstandard term for joint penetration and root penetration.
penetracion de soldadura. Un término fuera de norma para penetración de junta y penetración de raíz.

weld pool. The localized volume of molten metal in a weld prior to its solidification as weld metal.

charco de soldadura. El volumen localizado del metal derretido en una soldadura antes de su solidificación como metal de soldadura.

weld puddle. A nonstandard term for weld pool.
charco de soldadura. Un término fuera de norma para charco de soldadura.

weld reinforcement. Weld metal in excess of the quantity required to fill a joint. See also face reinforcement and root reinforcement.
refuerzo de soldadura. Metal de soldar en exceso de la cantidad requerida para llenar una junta. Vea también refuerzo de cara y refuerzo de raíz.

weld root. The points, shown in a cross section, at which the root surface intersects the base metal surfaces.
raíz de soldadura. Los puntos, enseñados en una sección transversa, la cual la superficie de la raíz se interseca con las superficies del metal base.

weld size. See preferred term size of weld.
tamaño de soldadura. Vea el término preferido tamaño de la soldadura.

***weld specimen.** A sample removed from a welded plate according to AWS specifications, which detail the preparation of the plate, the cutting of the plate, and the size of the specimen to be tested.
probeta de soldadura. Una prueba apartada del plato soldado de acuerdo con las especificaciones del AWS, las cuales detallan la preparación del plato, el corte del plato, y el tamaño de la probeta que se va a probar.

weld symbol. A graphical character connected to the welding symbol indicating the type of weld.
símbolo de soldadura. Un signo gráfico conectado al símbolo de soldadura indicando el tipo de soldadura.

weld tab. Additional material that extends beyond either end of the joint, on which the weld is started or terminated.
solera para soldar. Material adicional que se extiende más allá de cualquier punto de la junta en la cual la soldadura es empezada o terminada.

weld test. A welding performance test to a specific code or standard.
prueba de soldadura. Una prueba de ejecución de soldadura según una norma o código específico.

weld time (automatic arc welding). The time interval from the end of start time or end of upslope to beginning of crater fill time or beginning of downslope. Refer to the drawings for upslope time.
tiempo de soldadura (soldadura de arco automática). El intervalo de tiempo del fin del tiempo de arranque o el fin del pendiente en ascenso al principio del tiempo de llenar el crater o el principio del tiempo del pendiente en descenso. Refiérase al dibujo para tiempo del pendiente en ascenso.

weld timer. A device that controls only the weld time in resistance welding.
contador de tiempo para soldadura. Un aparato que controla solamente el tiempo de soldar en soldaduras de resistencia.

weld toe. The junction of the weld face and the base metal.
pie de la soldadura. La unión de la cara de la soldadura y el metal base.

weldability. The capacity of a material to be welded under the imposed fabrication conditions into a specific, suitably designed structure performing satisfactorily in the intended service.
soldabilidad. La capacidad de un material para soldarse bajo las condiciones de fabricación impuestas en un específico, en un diseño de estructura adecuada y para ejecutar satisfactoriamente los servicios intentados.

welder. One who performs manual or semiautomatic welding.
soldador. Uno que ejecuta soldadura manual o semiautomática.

welder certification. Written verification that a welder has produced welds meeting a prescribed standard of welder performance.
certificación del soldador. Verificación escrita de que un soldador ha producido soldaduras que cumplen con la norma prescrita de la ejecución del soldador.

welder performance qualification. The demonstration of a welder's ability to produce welds meeting prescribed standards.
calificación de ejecución del soldador. La demostración de la habilidad del soldador de producir soldaduras que cumplen con las normas prescritas.

welder registration. The act of registering a welder certification or a photostatic copy thereof.
registración del soldador. El acto de registrar una certificación del soldador o una copia fotostata de ello.

welding. A joining process producing coalescence of materials by heating them to the welding temperature, with or without the application of pressure or by the application of pressure alone, and with or without the use of filler metal.
soldadura. Un proceso de unión que produce coalescencia de materiales calentándolos a la temperatura de soldadura, con o sin la aplicación de presión o por la aplicación de presión solamente, y con o sin el uso del metal de relleno.

welding arc. A controlled electrical discharge between the electrode and the workpiece that is formed and sustained by the establishment of a gaseous conductive medium, called an arc plasma.
arco de soldadura. Una descarga eléctrica controlada entre el electrodo y la pieza de trabajo que es formada y sostenida por el establecimiento de un medio conductivo gaseoso, llamado un arco de plasma.

welding cables. The work cable and electrode cable of an arc welding circuit. Refer to drawing for direct-current electrode positive.
cables para soldar. Los cables de pieza de trabajo y el portelectrodo de un circuito de soldadura de arco. Refierase al dibujo orriente directa con el electrodo positivo.

welding current. The current in the welding circuit during the making of a weld.
corriente para soldadura. La corriente en el circuito de soldar durante la hechura de una soldadura.

welding current (automatic arc welding). The current in the welding circuit during the making of a weld, but excluding upslope, downslope, start, and crater fill current. Refer to drawing for upslope time.

corriente de soldadura (soldadura de arco automático). La corriente en el circuito de soldar durante la hechura de una soldadura, pero excluyendo el pendiente en ascenso, pendiente en descenso, empiezo, y corriente par llenar el crater. Refiérase al dibujo para tiempo del pendiente en ascenso.

welding cycle. The complete series of events involved in the making of a weld. Refer to drawings for downslope time and upslope time.
ciclo de soldadura. Una serie completa de eventos envueltos en hacer una soldadura. Refiérase al dibujo para tiempo de cáida del pendiente y tiempo del pendiente en descenso.

welding electrode. A component of the welding circuit through which current is conducted and that terminates at the arc, molten conductive slag, or base metal. See also arc welding electrode, bare electrode, carbon electrode, composite electrode, covered electrode, electroslag welding electrode, emissive electrode, flux cored electrode, lightly coated electrode, metal cored electrode, metal electrode, resistance welding electrode, stranded electrode, and tungsten electrode.
soldadura con electrodo. Un componente del circuito de soldar por donde la corriente es conducida y que termina en el arco, en la escoria derretida conductiva, o en el metal base. Vea también electro para soldar de arco, electrodo descubierto, electrodo de carbón, electrodo compuesto, electrodo cubierto, electrodo para soldadura de electroescoria, electrodo emisivo, electrodo de núcleo de fundente, electrodo con recubrimiento ligero, electrodo de metal de núcleo, electrodo de metal, electrodo para soldadura por resistencia, electrodo cable, y electrodo de tungsteno.

welding filler metal. The metal or alloy to be added in making a weld joint that alloys with the base metal to form weld metal in a fusion welded joint.
metal de soldadura para rellenar. El metal o aleación que se va a agregar en la hechura de una junta de soldadura que se mezcla con el metal base para formar metal de soldadura en una junta de fusión de soldadura.

welding generator. A generator used for supplying current for welding.
generador para soldar. Un generador que se usa para proporcionar la corriente para la soldadura.

welding ground. A nonstandard and incorrect term for workpiece connection.
tierra de soldadura. Un término fuera de norma e incorrecto para conexión de pieza de trabajo.

welding head. The part of a welding machine in which a welding gun or torch is incorporated.
cabeza de soldar. La parte de una máquina para soldar la cual una pistola de soldadura o una antorcha se puede incorporar.

***welding helmet.** See helmet
casco para soldar. Ver casco.

welding leads. The work lead and electrode lead of an arc welding circuit. Refer to drawing for direct-current electrode positive.
cables para soldar. Los cables de pieza de trabajo y el portelectrodo de un circuito de soldadura de arco. Refiérase al dibujo corriente directa con el electrodo positivo.

welding machine. Equipment used to perform the welding operation. For example, spot welding machine, arc welding machine, seam welding machine, etc.
máquina para soldar. El equipo que se usa para ejecutar la operación de soldadura. Por ejemplo, máquina de soldadura por puntos, máquina de soldadura de arco, máquina de soldadura de costura, etc.

welding operator. One who operates adaptive control, automatic, mechanized, or robotic welding equipment.
operador de soldadura. Uno que opera control adaptivo, automático, mecanizado, o equipo robótico para soldar.

welding position. See flat position, horizontal position, horizontal fixed position, horizontal rolled position, overhead position, and vertical position.
posición de soldadura. Vea posición plana, posición horizontal, posición fija horizontal, posición horizontal rodada, posición de sobrecabeza, y posición vertical.

POSITION OF WELDING

Flat. See **flat position**
Horizontal. See **horizontal position, horizontal fixed position, and horizontal rolled position.**
Vertical. See **vertical position.**
Overhead. See **overhead position.**

POSITION FOR QUALIFICATION

Plate welds

Groove welds

1G.	See **flat position.**
2G.	See **horizontal position.**
3G.	See **vertical position.**
4G.	See **overhead position.**

Fillet welds

1F.	See **flat position.**
2F.	See **horizontal position.**
3F.	See **vertical position.**
4F.	See **overhead position.**

Pipe welds

Groove welds

1G.	See **horizontal rolled position.**
2G.	See **vertical position.**
3G.	See **horizontal fixed position.**
5G.	Inclined position.
5GR.	Inclined position.

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welding power source. An apparatus for supplying current and voltage suitable for welding. See also welding generator, welding rectifier, and welding transformer.
fuente de poder para soldar. Un aparato para surtir corriente y voltaje adecuado para soldar. Vea también generador para soldar, rectificador para soldar, y transformador para soldar.

welding procedure qualification record (WPQR). A record of welding variables used to produce an acceptable test weldment and the results of tests conducted on the weldment to qualify a welding procedure specification.
registrodecalificacióndeprocedimientodelasoldadura (WPQR). Un registro de los variables usados para producir una probeta aceptable y los resultados de la prueba conducida en la probeta para calificar el procedimiento de especificación.

Welding Procedure Specification (WPS). A document providing in detail the required variables for specific application to ensure repeatability by properly trained welders and welding operators.
calificación de procedimiento de soldadura (WPA). Un documento que provee en detalle los variables requeridos para la

aplicación específica para asegurar la habilidad de repetir el procedimiento por soldadores y operadores que estén propiamente preparados.

welding process. A materials joining process that produces coalescence of materials by heating them to suitable temperatures, with or without the application of pressure or by the application of pressure alone, and with or without the use of filler metal.
proceso para soldar. Un proceso para unir materiales que produce coalescencia calentándolos a una temperatura adecuada con o sin la aplicación de presión solamente y con o sin usarse material para rellenar.

welding rectifier. A device in a welding machine for converting alternating current to direct current.
rectificador para soldar. Un aparato en una máquina para soldar para convertir la corriente alterna a corriente directa.

welding rod. A form of welding filler metal, normally packaged in straight lengths, that does not conduct the welding current.
varilla para soldar. Una forma de metal de soldadura para rellenar, normalmente empaquetada en piezas derechas, que no conduce la corriente para soldar.

welding sequence. The order of making the welds in a weldment.
orden de sucesión. La orden de hacer las soldaduras de una estructura soldada.

welding symbol. A graphical representation of a weld.
símbolo de soldadura. Una representación gráfica de una soldadura.

welding technique. The details of a welding procedure that are controlled by the welder or welding operator.
ejecución de soldadura. Los detalles del procedimiento que son controlados por el soldador u operador de soldadura.

welding tip. A welding torch tip designed for welding.
boquilla (punta) para soldar. Una boquilla en la antorcha de soldadura que está diseñada para soldar.

welding torch (arc). A device used in the gas tungsten and plasma arc welding processes to control the position of the electrode, to transfer current to the arc, and to direct the flow of shielding and plasma gas.
antorcha para soldar (arco). Un aparato usado en los procesos de soldadura del gas tungsteno y arco plasma para controlar la posición del electrodo, para transferir corriente al arco, y para dirigir la corriente del gas protector y gas de la plasma.

welding torch (oxyfuel gas). A device used in oxyfuel gas welding, torch brazing, and torch soldering for directing the heating flame produced by the controlled combustion of fuel gases.
antorcha para soldar (gas oxicombustible). Un aparato usado en soldadura de gas oxicombustible, soldadura blanda con antorcha y soldadura fuerte con antorcha y para dirigir la llama para calentar producida por la combustión controlada de gases de combustión.

welding transformer. A transformer used to supplying current for welding. See also reactor (arc welding).
transformador para soldar. Un transformador que se usa para dar corriente para la soldadura. Vea también reactor (soldadura de arco).

welding voltage. See arc voltage.
voltaje para soldar. Vea voltaje del arco.

welding wire. A form of welding filler metal, normally packaged as coils or spools, that may or may not conduct electrical current, depending upon the filler metal and base metal in a solid state weld with filler metal.
alambre para soldar. Una forma de metal para rellenar con soldadura, normalmente empaquetado en rollos o en carretes que pueda o pueda que no conducir corriente eléctrica, dependiendo en el metal de relleno y el metal base en una soldadura que está en estado sólido con metal de relleno.

weldment. An assembly whose component parts are joined by welding.
conjunto de partes soldadas. Una asamblea cuyas partes componentes están unidas por la soldadura.

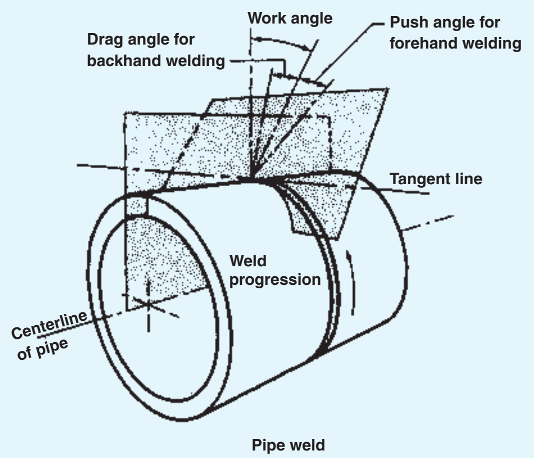
weldor. See preferred term welder.
soldador. Vea el término preferido soldador.

wetting. The phenomenon whereby a liquid filler metal or flux spreads and adheres in a thin, continuous layer on a solid base metal.
exudación. El fenómeno de que un metal para rellenar líquido o un flujo se puede desparramar y adherirse en una capa delgada, capa continua en un sólido metal base.

wire-feed speed. The rate at which wire is consumed in arc cutting, thermal spraying, or welding.
velocidad de alimentador de alambre. La velocidad que el alambre es consumido en cortes de arco, rociado termal, o soldadura.

work angle. The angle less than 90° between a line perpendicular to the major workpiece surface and a plane determined by the electrode axis and the weld axis. In a tee joint or a corner joint, the line is perpendicular to the nonbutting member. This angle can also be used to partially define the position of guns, torches, rods, and beams.
ángulo de trabajo. El ángulo menos de 90° entre una línea perpendicular a la superficie de pieza de trabajo mayor y una plana determinada por el eje del electrodo y el eje de la soldadura. En una junta-T o en una junta de esquina, la línea es perpendicular a un miembro que no topa. Este ángulo puede ser usado también para parcialmente definir la posición de pistolas, antorchas, varillas, y rayos.

work angle (pipe). The angle less than 90° between a line perpendicular to the cylindrical pipe surface at the point of intersection of the weld axis and the extension of the electrode axis, and a plane determined by the electrode axis and a line tangent to the pipe at the same point. In a T-joint, the line is perpendicular to the nonbutting member. This angle can also be used to partially define the position of guns, torches, rods, and beams.
ángulo de trabajo (tubo). El ángulo menos de 90° entre una línea, la cual es perpendicular a la superficie de un tubo cilíndrico al punto de intersección del eje de la soldadura y la extensión del eje del electrodo, y un plano determinado por el eje del electrodo y una línea tangente al tubo al mismo punto. En una junta-T, la línea es perpendicular a un miembro que no topa. Este ángulo puede también usarse para definir parcialmente la posición de pistolas, antorchas, varillas, y rayos.



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work connection. The connection of the work lead to the work. Refer to drawing for **direct-current electrode negative.**
pinza de tierra. La conexión del cable de trabajo (tierra) al trabajo. Refiérase al dibujo para **corriente directa con electrodo negativo.**

work lead. The electric conductor between the source of arc welding current and the work. Refer to drawing for **direct-current electrode negative.**
cable de tierra. Un conductor eléctrico entre la fuente de la corriente del arco y la pieza de trabajo. Refiérase al dibujo **corriente directa con electrodo negativo.**

working envelope. The set of points representing the maximum extent or reach of the robot hand or working tool in all directions.
alcance de operación. Un juego de puntos que representan la máxima extensión o alcance de la mano del robot o la herramienta del trabajo en todas las direcciones.

***working pressure.** The pressure at the low-pressure gauge, ranging from 0 psi to 45 psi (depending on the type of gas), used for welding and cutting.
presión de trabajo. La presión en el manómetro de baja presión, con escala de 0 psi a 45 psi (dependiendo en el tipo de gas), usado para cortar y soldar.

working range. All positions within the working envelope. The range of any variable within which the system normally operates.
extensión de trabajo. Todas las posiciones dentro del alcance del trabajo. El alcance de cualquier variable dentro del sistema que opera normalmente.

workpiece. An assembly, component, member, or part in the process of being manufactured.
pieza de trabajo. La parte que está soldada, con soldadura fuerte, soldadura blanda, corte termal, o rociado termal.

workpiece connection. A device (clamp) used to provide an electrical connection between the workpiece and the workpiece lead.
conexion de pieza de trabajo (abrazadera). La conexión del cable de la pieza de trabajo a la pieza de trabajo.

workpiece lead. A secondary circuit conductor transmitting energy from the power source to the workpiece connection.
cable de pieza de trabajo. El conductor eléctrico entre la fuente de corriente de soldadura de arco y la conexión de la pieza de trabajo.

workstation. A manufacturing unit consisting of one or more numerically controlled machine tools serviced by a robot.
estación de trabajo. Una unidad manufacturera de una o más herramienta numerada que es controlada por una máquina y abatecida por un robot.

wrist. A set of rotary joints between the arm and hand that allows the hand to be oriented to the workpiece.
muñeca. Un juego de coyunturas rotatorias entre el brazo y la mano que permite a la mano ser orientada a la pieza de trabajo.

X

***X-axis.** Machine, automated, or robotic movement in a longitudinal direction.
eje X. Movimiento mecánico, automatizado o robótico en dirección longitudinal.

Y

yaw. The angular displacement of a moving body about an axis that is perpendicular to the line of motion and to the top side of the body.
guiñada. El desalojamiento de un cuerpo en movimiento alrededor de un eje que está perpendicular a la línea de movimiento y al lado más alto del cuerpo.

***Y-axis.** Machine, automated, or robotic movement in a transverse direction.
eje Y. Movimiento mecánico, automatizado o robótico en dirección transversal.

Z

***Z-axis.** Machine, automated, or robotic movement in a vertical direction.
eje Z. Movimiento mecánico, automatizado o robótico en dirección vertical.

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